Guide to Pavement Technology Part 4L

Stabilising Binders

Austroads

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Guide to Pavement Technology Part 4L: Stabilising Binders

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Abstract

Austroads has undertaken to produce a comprehensive library of guides which cover the design, construction, maintenance and operation of the road network for use by road authorities in Australia and New Zealand.

Stabilisation may be defined as a process by which the intrinsic properties of a pavement material are altered by the addition of a stabilisation binder to meet performance expectations in its operating, geological and climatic environment. Part 4L of the Guide to Pavement Technology describes the types of binders most commonly used in the manufacture of stabilised pavement materials either by in situ construction practices or plant-mixed operations.

The types of binders described are; lime, cement, cementitious pozzolans, bitumen, chemical and synthetic polymers. Information on the selection of the most appropriate binder type and quantity required for stabilisation of a particular material may be found in the Austroads Guide to Pavement Technology: Part 4D – Stabilised Materials.

Keywords

pavement stabilisation, binders, lime, bitumen, cement, polymers, ligno-sulphonates

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About Austroads

Austroads is the peak organisation of Australasian road transport and traffic agencies.

Austroads’ purpose is to support our member organisations to deliver an improved Australasian road transport network. To succeed in this task, we undertake leading-edge road and transport research which underpins our input to policy development and published guidance on the design, construction and management of the road network and its associated infrastructure.

Austroads provides a collective approach that delivers value for money, encourages shared knowledge and drives consistency for road users.

Austroads is governed by a Board consisting of senior executive representatives from each of its eleven member organisations:

- Roads and Maritime Services New South Wales
- Roads Corporation Victoria
- Queensland Department of Transport and Main Roads
- Main Roads Western Australia
- Department of Planning, Transport and Infrastructure South Australia
- Department of State Growth Tasmania
- Department of Infrastructure, Planning and Logistics Northern Territory
- Transport Canberra and City Services Directorate, Australian Capital Territory
- Australian Government Department of Infrastructure and Regional Development
- Australian Local Government Association
- New Zealand Transport Agency.

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1. Introduction

Austroads has undertaken to produce a comprehensive library of guides which cover the design, construction, maintenance and operation of the road network for use by road authorities in Australia and New Zealand.

Austroads guides are intended to be a reference for road authorities and to promote national consistency and harmonisation. They represent an agreed approach to the work road authorities undertake in relation to the road network. Austroads member organisations have agreed to adopt Austroads guides as the basis of their operation. Where practice in a jurisdiction differs from a guide, arising from specific jurisdictional circumstances, then that jurisdiction will produce a jurisdictional supplement to that guide.

1.1 Guide to Pavement Technology

The Guide to Pavement Technology consists of the following parts:

- Part 1: Introduction to Pavement Technology
- Part 2: Pavement Structural Design
- Part 3: Pavement Surfacings
- Part 4: Pavement Materials
  - Part 4A: Granular Base and Subbase Materials
  - Part 4B: Asphalt
  - Part 4C: Materials for Concrete Road Pavements
  - Part 4D: Stabilised Materials
  - Part 4E: Recycled Materials
  - Part 4F: Bituminous Binders
  - Part 4G: Geotextiles and Geogrids
  - Part 4H: Test Methods
  - Part 4I: Earthworks Materials
  - Part 4J: Aggregate and Source Rock
  - Part 4K: Seals
  - Part 4L: Stabilising Binders
- Part 5: Pavement Evaluation and Treatment Design
- Part 6: Unsealed Pavements
- Part 7: Pavement Maintenance
- Part 8: Pavement Construction
- Part 9: Pavement Work Practices
- Part 10: Sub-Surface Drainage.

1.2 Scope

Part 4L of the Guide to Pavement Technology discussed the types of various stabilising binders used in road construction (lime, cement, bitumen, slag, fly ash and chemicals), their properties, manufacture, and chemical reactions during the stabilisation process and safety considerations associated with their use.

Topics related to stabilising binders and addressed in other parts of the Guide to Pavement Technology are listed in Table 1.1. Relevant websites from which pertinent publications (technical notes, guidelines, work tips and safety data) on technologies associated with stabilising binders can be obtained are listed in Table 1.2.

Relevant New Zealand road construction specifications and notes are located at: http://www.transit.govt.nz/technical/specifications.jsp.

Table 1.1: References to stabilising binders in the Austroads Guide to Pavement Technology

Pavement design	Part 2: Pavement Structural Design
Pavement material selection	Part 4: Pavement Materials Part 4E: Pavement Materials – Recycled Materials Part 4I: Pavement Materials – Earthworks Materials Part 6: Unsealed Pavements
Stabilisation	Part 4: Pavement Materials Part 4D: Pavement Materials – Stabilised Materials Part 4I: Pavement Materials – Earthworks Materials Part 4L: Pavement Materials – Stabilising Binders
Construction practice/specifications	Part 8: Pavement Construction Part 9: Pavement Work Practices
Maintenance practice	Part 7: Pavement Maintenance Part 9: Pavement Work Practices
Asset management	Part 5: Pavement Evaluation and Treatment Design
Bituminous sealing of existing unsealed road pavements	Part 3: Pavement Surfacings Part 4: Pavement Materials Part 4K: Pavement Materials – Seals

Table 1.2: Key websites pertinent to stabilising binders technology

Austroads	**www.austroads.com.au**
ARRB Group	www.arrb.com.au
NZ Transport Agency	www.nzta.govt.nz
Australian Stabilisation Industry Association	www.auststab.com.au
Australian Asphalt Pavement Association	www.aapa.asn.au
Cement Concrete & Aggregates Australia	www.concrete.net.au
Materials Safety	www.msds.com.au
South African National Roads Agency	www.nra.co.za

2. General

Stabilisation binders used in road construction are manufactured to either specific Australian Standards or road authority specifications. There are several ways to categorise binder types and this guide has chosen a format in common usage in Australia and New Zealand, viz:

- lime AS1672.1, TNZ M/15
- cement AS3972, NZS 3122
- hot bitumen AS2008, TNZ M/01 (for foaming)
- bitumen emulsion AS2341, TNZ M/01 (for emulsifying)
- slag AS3582.2
- fly ash AS3582.1
- chemicals there are no recognised standards
- synthetic polymers.

Stabilisation binders are categorised in terms of their main constituent, viz:

- lime: hydrated lime [$Ca(OH)_2$] and quicklime [CaO]
- cement: includes normal Portland (GP), and blended (GB) cements
- cementitious: a combination of pozzolan material and cement and/or lime:
  - lime[1] and fly ash
  - lime and slag (ground granulated blast furnace slag)
  - lime, slag and fly ash
  - cement and slag
  - cement and lime
  - cement, lime and fly ash
  - cement, slag and fly ash
- bitumen: Class C170 bitumen is typically used in stabilisation:
  - foamed bitumen
  - bitumen emulsion

Bitumen stabilisation may incorporate a supplementary binder, i.e. lime or cement.

- chemical: proprietary products primarily including lignin derivatives
- synthetic polymers: generally based upon polyvinyl acetate (PVA), polyvinyl chloride (PVC) and polyacrylimide (PAM).

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[1] All blends incorporating lime require hydrated lime for the cementing process. This may be derived from direct addition of hydrated lime. However, it is common practice to simply refer to lime.

3. Lime

3.1 Lime Manufacture

The manufacture of quicklime involves the heating of limestone in a lime kiln to temperatures above 900 °C resulting in carbon dioxide being driven off and calcium oxide being produced (Figure 3.1). The chemical equation is as follows:

$$\begin{array}{ccc} \mathrm{CaCO_3} + \text{heat} & \longrightarrow & \mathrm{CaO + CO_2} \\ \text{(Calcium Carbonate)} & \longleftarrow & \text{(Calcium Oxide)} \\ \text{(Limestone)} & & \text{(Quicklime)} \end{array} \qquad \mathbf{1}$$

(Heat of dissociation ~ 760 kcal/kg of CaO)

Limestone feedstocks for calcination are not pure calcium carbonate and the kilning processes have inherent inefficiencies. This means that commercial quicklime will never be 100% CaO.

At temperatures below 350 °C, the calcium oxide component of quicklime reacts with water to produce hydrated lime (calcium hydroxide) as well as liberating heat (Figure 3.1). The following equation shows that (stoichiometrically) 56 unit weights of CaO (pure) will hydrate (be ‘slaked‘) with 18 unit weights of water. Consequently, it would need 320 litres of water to hydrate one tonne of CaO.

$$\begin{array}{ccc} \mathrm{CaO + H_20} & \longleftarrow & \mathrm{Ca\,(OH)_2} + \text{heat} \\ \text{(Calcium Oxide)} & \longrightarrow & \text{(Calcium Hydroxide)} \\ \text{(Quicklime)} & & \text{(Hydrated Lime)} \end{array} \qquad \mathbf{2}$$

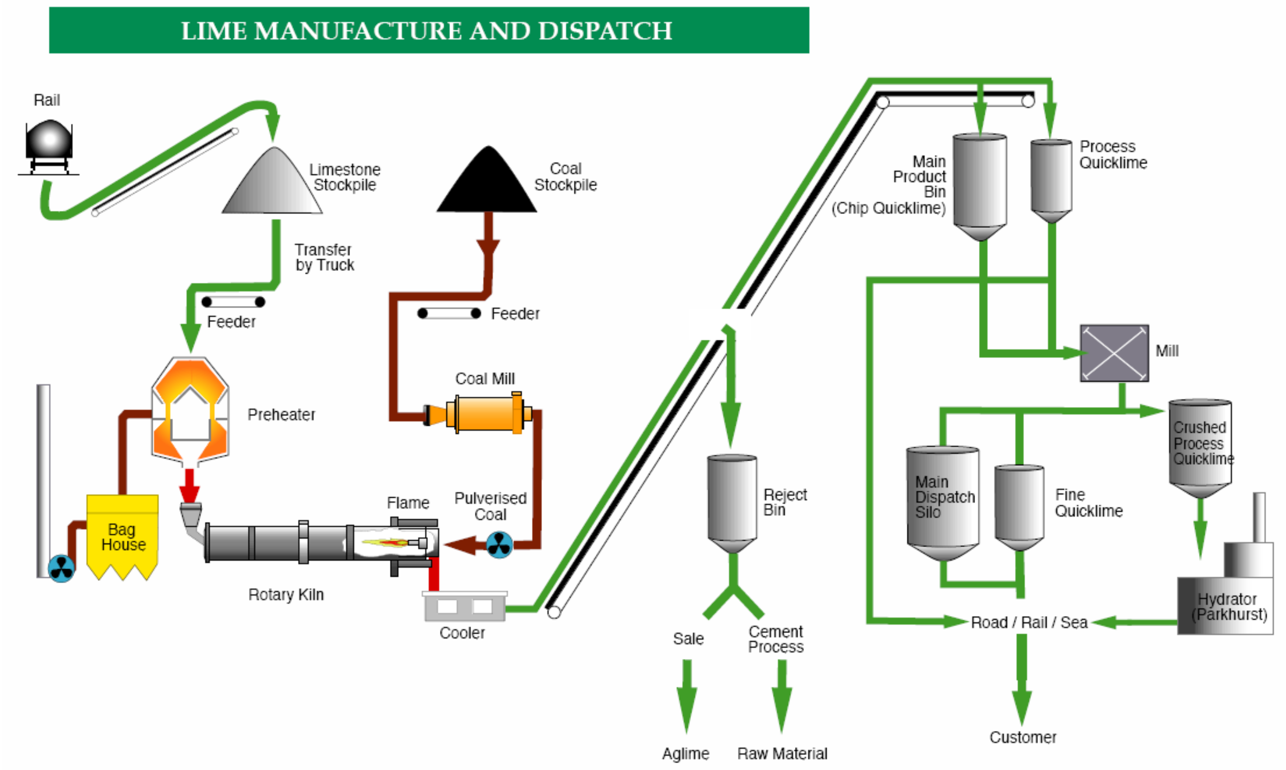
(Heat of hydration ~ 272 kcal/kg CaO)

The lime manufacturing process is shown in Figure 3.2.

Figure 3.1: Quicklime slaking in tanker or when spread on roadway prior to mixing

Source: ARRB Group

Figure 3.2: Lime manufacture



Source: Cement Australia

In the laboratory, hydrated lime is used and the $Ca(OH)_2$ component determines its reaction with subgrade and pavement materials. In the field, quicklime is used extensively and slaked on site to form hydrated lime. As the available CaO in quicklime, and accordingly $Ca(OH)_2$ when slaked, varies with the source and manufacturer, a lime conversion factor is needed to determine the field spread rate for quicklime. In summary, hydrated lime used in the laboratory is not pure and quicklime used in the field varies significantly in the Available Lime Index[2] among sources. For more information on the conversion of hydrated lime to quicklime refer to AustStab Technical Note No. 1 (AustStab 2008a). Readers are also referred to Part 9 of the Guide to Pavement Technology: Pavement Work Practices.

In stabilisation technology both quicklime and hydrated lime are commonly addressed as lime. However attention is drawn to Table 3.1, where it is noted that quicklime has approximately 30% more effective lime for stabilisation than hydrated lime which can be taken into account in the mix design. Lime contents in specifications are expressed as being hydrated lime (i.e. Available Lime Index = 100%). Lime slurries are no longer used in Australia for pavement and subgrade stabilisation works.

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[2] As determined from AS 4489.6.1.

Table 3.1: Properties of lime (powdered form)

	Hydrated lime	Quicklime	Slurry lime
Composition	$Ca(OH)_2$	CaO	$Ca(OH)_2$
Form	Fine powder	Coarse powder	Slurry
Equivalent $Ca(OH)_2$/unit mass	1.00	1.32	0.56 to 0.33
Bulk density (t/m^3)	0.45 to 0.56	1.05	1.25

Note that, in New Zealand, quicklime is available in powdered form (up to 3 mm), in granules (up to 12 mm) and large granules (up to 19 mm). It is, however, imperative that these are slaked adequately if used to modify the material's plasticity.

In addition to quicklime and hydrated lime, other forms of lime are dolomite (calcium and magnesium carbonate) and agricultural lime (calcium carbonate). Agricultural lime and dolomite are not associated with pavement stabilisation. Dolomite may be burnt to form dolomitic lime (calcium and magnesium oxide) but this is not usually as effective as quicklime because of its relatively lower Available Lime Index.

3.1.1 Lime Binder Reaction in Stabilisation

Lime reacts with the soil in two ways:

- it agglomerates fine clay particles into coarse, friable particles by a base exchange with the calcium cation (of the lime) displacing sodium or hydrogen ions with a subsequent 'dewatering' of the clay
- it raises the pH to above 12, which encourages chemical reactions that lead to the formation of calcium silicates and aluminates.

These calcium complexes initially form as a gel which coats and binds soil particles as the chemical processes move toward the crystallisation (cementitious) stage as they form hydrates. The rate of crystallisation is temperature dependent and may take many months to reach completion. This in turn correlates to a steady strength gain that can be tracked and measured using tests such as CBR or UCS.

Quicklime's ability to form alkaline solutions / suspensions in water is a key to it being able to modify certain soils in such a way that the end result is a benefit to road builders. The hydration complexes are cementitious products, similar in composition to those found in cement paste. They are the end results of physio-chemical reactions with clayey soil minerals (or other pozzolans such as slag) that dramatically reduce the plasticity of the soil, increase its workability and improve its compaction characteristics.

There are, however, significant differences in the nature and rate of the cementitious reactions and these differences often provide a basis for choice between cementitious stabilising binders and lime.

The factors which can affect the hydration of quicklime include:

- the inherent reactivity of the quicklime
- its mean apparent density and the distribution of its particle density
- its particle size distribution
- impurities which, if they were to form a surface layer on the quicklime particles, would inhibit the hydration process.

Lime stabilisation has an effect on the engineering properties of the material as detailed in Table 3.2.

Table 3.2: General properties of lime-stabilised materials

Property	Description
Plasticity	The Plasticity Index (PI) decreases, as much as four times in some circumstances. This is due to the Liquid Limit (LL) decreasing and the Plastic Limit (PL) increasing.
Moisture-density relationship	The result of immediate reactions between lime and the clay soil is a substantial change in the moisture-density relationship. The moisture-density changes reflect the new nature of the soil and are evidence of the physical property changes occurring in the soil upon lime treatment.
Swell potential	Soil swell potential and swelling pressures are normally significantly reduced by lime treatment.
Drying	Lime (particularly quicklime) aids the immediate drying of wet clay soils. This allows compaction to proceed more quickly.
Strength properties	Both the Unconfined Compressive Strength (UCS) and the CBR increase considerably with the addition of lime. These values can be further increased by a follow-up treatment of cement after the initial lime treatment. Experience has shown increases of CBRs from three up to twenty with lime-only treatment and as high as CBR 50 with a follow-up cement treatment. The gain in strength can be used in the design of pavements to determine the required overall pavement depth. A balance of stiffness versus support (modular ratio) should be maintained.
Water resistance	The lime-stabilised layer forms a water resistant barrier by impeding penetration of moisture from above and below. Thus, the layer becomes a working platform which sheds water and allows construction to proceed unaffected by weather. Experience in Victoria is that a second treatment with cement is required to achieve long-term waterproofing of the clay-stabilised layer unless the stabilised layer is covered by another pavement layer as quickly as possible.

4. Cement

There are a variety of cement types and blends in Australia which are commercially produced and each has different properties and characteristics. The principal cement types available are:

- Type GP – general purpose Portland cement
- Type GB – general purpose blended cement.

General purpose cements are produced from a mixture of calcium carbonate, alumina, silica and iron oxide which, when calcined and sintered at high temperatures, produce a new group of chemical compounds capable of reacting with water. The composition of individual cements can vary depending on the nature and composition of the raw materials being used.

In Australia special purpose cements are not commonly used in stabilisation of subgrade soils or pavement materials. There are also some special class cements as discussed in Section 5.4.

4.1 General Purpose Portland Cement (GP)

Portland cement is defined in AS 3972 (Portland and Blended Cements) as:

> *a hydraulic cement which is manufactured as an homogeneous product by grinding together Portland cement clinker and calcium sulphate, and which, at the discretion of the manufacturer, may contain up to 5% of mineral additions.*

4.2 General Purpose Blended Cement (GB)

Blended cement is defined as a hydraulic cement containing Portland cement and a quantity comprised of one or both of:

- greater than 5% of fly ash or ground granulated iron blast furnace slag, or both
- up to 10% silica fume.

Both types of cement are used in stabilisation but there is an increasing trend towards the use of blended cements which allow the constructor longer working times to achieve better compaction and smoother riding surface. In addition, early trafficking to induce closely-spaced micro-cracks can minimise the risk of larger, wider-spaced shrinkage cracks appearing.

4.3 Cement Binder Reaction in Stabilisation

With cement binders, the primary reaction is the hydration reaction of the cement with water in the soil which leads to the formation of cementitious material (chains of calcium silicate and aluminum hydrates as in concrete). These reactions occur almost independently of the nature of the soil.

The hydration reaction releases hydrated lime (about 30% by mass of the added cement in the case of general purpose cement stabilisation) which can cause secondary reactions with any pozzolans within the soil. The secondary reaction produces cementitious products similar to those from the primary reaction.

The hydration reaction starts immediately on contact of the cementitious binder with water. It proceeds rapidly if cement is used and there are very significant strength gains in the first day. The secondary reactions produced using cement are similar to those that occur in lime stabilisation and proceed slowly with time.

5. Cementitious Binders

5.1 Pozzolanic Materials

Cementitious binders contain a pozzolanic additive which is a siliceous or alumino siliceous material that, in finely divided form and in the presence of moisture, chemically reacts at ordinary room temperatures with calcium hydroxide released by the hydration of Portland cement or lime to form compounds possessing cementitious products. Pozzolanic additives include fly ash and iron and steel slags which may be combined with lime or cement to form cementitious binders.

Cementitious binders provide an alternative to GP cement, on the grounds of economy or for extended working time for compaction and finishing.

5.2 Iron and Steel Slags

Approximately four million tonnes of iron and steel slags are produced in Australia annually. Therefore the recycling of these by-products as road stabilising binders contributes significantly to national waste management strategies.

The various types of slag are:

- blast furnace slag – known as BF slag of BFS
- basic oxygen steel slag – known as BOS slag or BOS (not used in road stabilisation)
- electric arc furnace slag – known as EAF slag or EAF (not used in road stabilisation).

A summary of the manufacturing processes and application of slags pertinent to road stabilisation is shown in Table 5.1.

Table 5.1: Types of slag used in road stabilisation

Slag source	Common nomenclature	Manufacturing process	Applications pertinent to stabilised pavements
Blast furnace iron slag	Rock slag or air cooled slag	Crushing and screening slag which has been slowly air cooled	Granular pavement layers which may become naturally bound over time
	Granulated slag or slag sand	Rapidly quenching molten slag with high pressure – high volume water sprays	Stabilisation binder Subbase layers which may become naturally bound over time
	Ground granulated slag or GGBFS	Grinding granulated slag to cement fineness	Stabilisation binder
Basic oxygen steel slag	BOS slag or steel furnace slag	Crushing and screening slag which has been slowly air cooled	Granular pavement layers which may become naturally bound over time
Electric arc furnace steel slag	EAF slag or steel furnace slag	Crushing and screening slag which has been slowly air cooled	Granular pavement layers which may become naturally bound over time

Source: Modified from Australian Slag Association (2002)

Crushed slags used as granular pavement generally conform to the standard specifications (particle size distribution, plasticity and hardness) required by road authorities. The monitoring of pavements that were constructed from these materials 20 years ago has indicated that a fully bound material with a UCS >10 MPa has been realised by natural cementation. However, this property of self-cementation is particular to the slag source and should not be taken as a general property, and the self-cementing action does not always perform in the long term.

Generally in road stabilisation ground granulated blast furnace slag (GGBFS) is used. It is often manufactured pre-blended with lime as a proprietary product. GGBFS should conform to AS 3582.2. It is commonly sourced from Wollongong in NSW or imported.

GGBFS, which will act as a slow-setting hydraulic cement by itself, reacts exceptionally well with lime and so it is an excellent pozzolanic material and is treated as such in this Guide. Some ground slag materials already contain small amounts of free lime but the minimum lime content required for the reaction is one part lime for each ten parts slag.

The most common combination of slag/lime blends is 85:15. In addition to Accelerated Loading Facility (ALF) trials (Jameson et al. 1995; Moffatt et al. 1998) demonstrating the performance of slag-lime in bound pavement stabilisation, it has been successfully used on Australian roads (NSW) for at least the past ten years.

5.3 Fly Ash

Fly ash is a product of the power generation industry. The type of coal used and the mode of operation of the plant determine the chemical composition and particle size distribution. Consequently, not all sources of fly ash are suitable for stabilisation. Generally, fly ash derived from burning black coal is high in silica and alumina and low in calcium and carbon and, as such, is well suited for use in stabilisation. Fly ash derived from burning brown coal contains large percentages of calcium and magnesium sulphate and chlorides and other soluble salts and is unsuitable for use in stabilisation.

Unburned organic carbon breaks the continuity of contact in the cementitious reactions and should be limited to about 10%.

Fly ash should conform to AS 3582.1 and be ‘fine grade type’, i.e. that solid material extracted from the flue gases of a pulverised coal fed boiler that has at least 75% passing the 45 micron sieve size and also a maximum 4% loss on ignition.

5.4 Cementitious Binder Reactions in Stabilisation

Pozzolanic reactions are usually slow but continue over a long period provided that adequate moisture is present. Studies conducted by RTA NSW on lime slag-stabilised pavements indicate strength gains from a UCS of 3 MPa at construction to 13 MPa after 10 years (RTA NSW 2004).

Reactions are also temperature sensitive, the rate of reaction increasing with increasing temperature. Organic material and sulphate found in the pavement material may cause retardation of the reaction.

The best results from stabilisation with supplementary cementitious material depend on the amounts of lime, pozzolan and pavement material. Typical commercial blends are shown in Table 5.2. In this Table, SL refers to ‘Shrinkage Limited’ cement, which is a special class of cement under AS3972-1997. It is one of four special classes in addition to the two general classes of GP and GB described in Section 4. The four special classes are:

- HE high early strength
- LH low heat
- SR sulphate resisting

- SL shrinkage limited.

Usually the amount of lime plus fly ash added to a pavement material should not exceed about 5% by mass of pavement material. These proportions should be confirmed by testing.

In the selection of a cementitious binder the working time available prior to hydration can be determined in the laboratory, viz. VicRoads RC 330.02 and RTA T147.

Table 5.2: Typical range of commercial cementitious binder pozzolan blends

Slag/lime blends	
Stabilment	85% slag, 15% lime
30 lime blend	30% slag, 70% lime
50 lime blend	50% slag, 50% lime
60 lime blend	60% slag, 40% lime
70 lime blend	70% slag, 30% lime
Cement/fly ash blends	
road pozzolan	75% SL cement*, 25% fly ash
road pozzolan 20	80% SL cement*, 20% fly ash
road pozzolan 50	50% SL cement*, 50% fly ash
pozzolan blend 10	90% SL cement*, 10% fly ash
Slag/cement blends	
SSC40	60% slag, 40% SL cement*
SSC50	50% slag, 50% SL cement*
Cement/lime blends	
80/20 blend	80% slag/lime, 20% lime
50 cement blend	50% slag/lime, 50% lime
Fly ash/lime blends	
50 ash blend	50% fly ash, 50% slag/lime
75/25 ash/lime	75% fly ash, 25% lime
Triple blends	
523 slag t blend	50% slag, 20% lime, 30% fly ash
532 slag t blend	50% slag, 30% lime, 20% fly ash
352 lime t blend	30% slag, 50% lime, 20% fly ash
622 cement t blend	60% SL cement*, 20% slag, 20% fly ash
225 ash t blend	25% slag, 25% lime, 50% fly ash
424 triple blend	20% slag, 40% SL cement*, 40% fly ash
442 triple blend	40% slag, 40% SL cement*, 20% fly ash
424 slag triple blend	40% slag, 20% lime, 40% fly ash

**'Shrinkage Limited' cement*
Source: Blue Circle Southern Cement

6. Bitumen

Bituminous stabilisation may be carried out with:

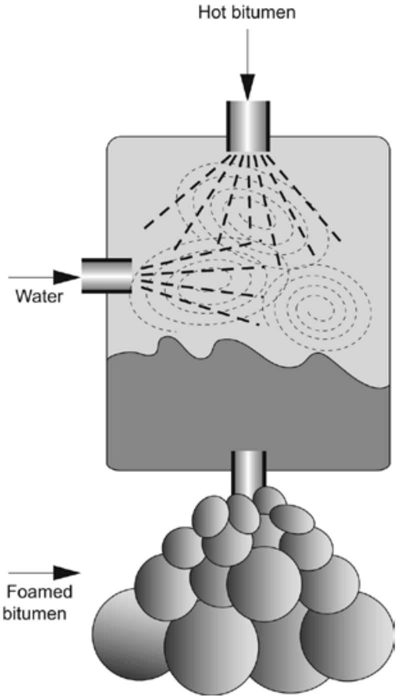
- foamed bitumen
- bitumen emulsion, either as cationic or anionic emulsion.

In association with bitumen stabilisation secondary binders, usually lime or cement can be added to increase the stiffness of the mix.

6.1 Stabilisation with Foamed Bitumen

Foamed bitumen is a mixture of air, water and hot bitumen. Injecting a small quantity of cold water into hot bitumen produces an instantaneous expansion of the bitumen, up to 15 times its original volume. The concept of manufacturing foamed bitumen is illustrated in Figure 6.1.

Figure 6.1: Manufacture of foamed bitumen

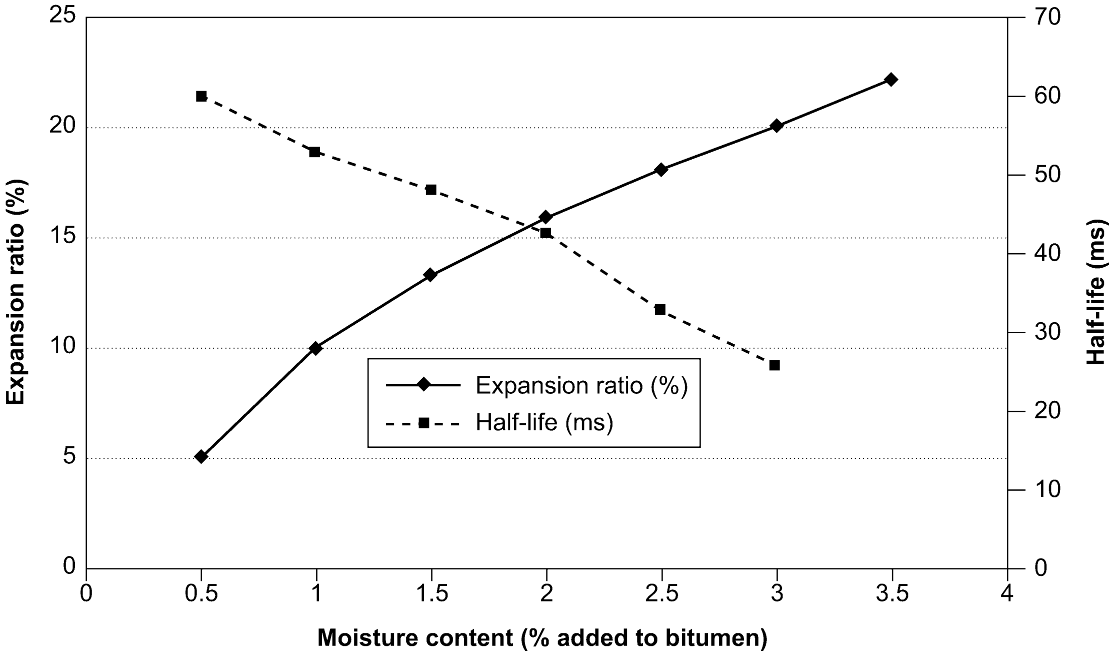


Source: Wirtgen

The increased surface area enhances the bitumen’s viscosity to enable mixing with damp and cold aggregates. Only the fine particles within the aggregate are encapsulated by the bitumen, thereby creating a bitumen-rich mortar that binds the matrix together. The foamed bitumen collapses very quickly and therefore rapid mixing is required to adequately disperse the bitumen throughout the material.

The influence of water content on the foaming characteristics of bitumen affects both the expansion ratio (increase in volume) and the half-life (time for half the expanded volume to collapse). An example is shown in Figure 6.2.

Figure 6.2: Example of the effect of water on foaming characteristics

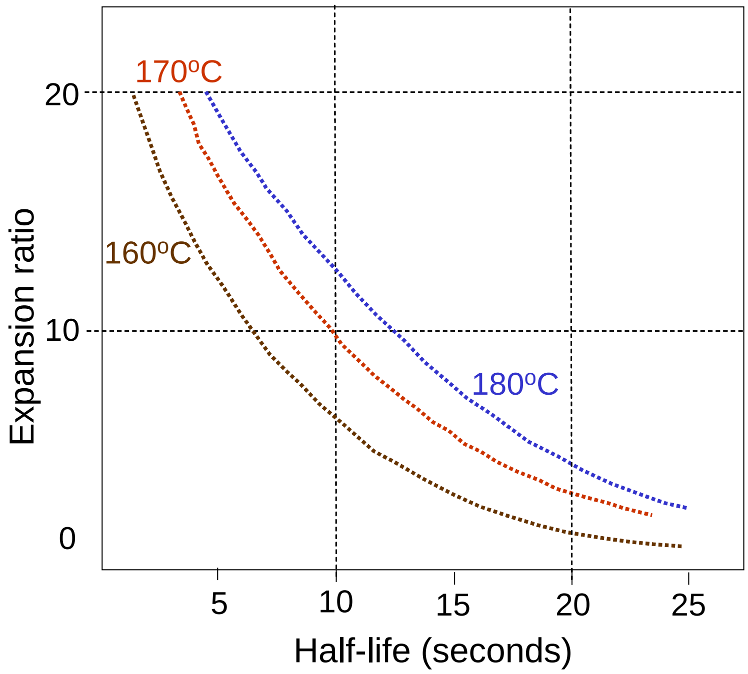


Source: Kendall et al. (2001)

In addition, as the bitumen temperature decreases slightly below 180 ºC, the half-life duration reduces and this can have an effect on the foaming process. An example is shown in Figure 6.3. Moisture content also varies from left to right along the horizontal axis in Figure 6.2 but it is not significant enough to change the impact on the half-life for different bitumen temperatures.

Guidance for the use of foamed bitumen in NZ can be found in Roading New Zealand Technical Note 001 (RNZ 2007).

Figure 6.3: Example of the effect on expansion ratio and half-life at different bitumen temperatures



Source: Wirtgen

6.2 Stabilisation with Bitumen Emulsion

Bitumen emulsions are dispersions of fine droplets of bitumen in water. Standard grades comprise approximately 60% bitumen and 40% water with a small proportion of emulsifier. However, higher bitumen content emulsions may have up to 80% bitumen content. Some types of emulsions include additives such as polymer or cutter and different proportions of bitumen. The setting and curing of emulsions involves the separation and removal of water (‘breaking’) leaving solid bitumen. The type and quantity of emulsifier determines the setting characteristics of the emulsion.

Another type of emulsions are those termed ‘high float’ emulsions which are manufactured from Class 170 binder with additives that make the residual binder more tolerant over a range of in-service temperatures. They provide a thick coating of binder to the aggregates without excessive binder drain off (VicRoads 2005).

Bitumen emulsions are manufactured to comply with AS 1160 which allows for two classes depending on the charge of the suspended particles, viz:

- anionic bitumen emulsion, where the particles of bitumen are negatively charged
- cationic bitumen emulsion, where the particles of bitumen are positively charged.

Both classes of bitumen emulsion are prepared in two grades: rapid setting (RS) and slow setting (SS). The emulsion needs to be formulated in such a way that the bitumen emulsion breaks at or near the time of primary compaction. Usually slow-setting to medium-setting bitumen emulsions are suitable; this depends largely on the type of aggregates that are being treated.

Most suppliers manufacture all classes and grades. However, emulsions of the same class made by different suppliers can react differently with the same soil. It is therefore important that the emulsion to be used in the field be evaluated in a laboratory testing program. More than one product should be tested to provide an appropriate assessment of the types of bitumen emulsion proposed.

6.3 Bitumen with Secondary Binders

The stabilisation of gap-graded granular materials and/or materials with smooth, rounded grains can be improved by the addition of mineral filler, rock dust, fly ash, etc. Hydrated lime (1-2%) may also be used as a secondary binder to improve particle coating. Lime may also be used as a preliminary modifying treatment to render particular pavement materials more amenable to receiving a bituminous stabilising binder.

The addition of lime has the effect of stiffening the bitumen and hence the mix as well as acting as an anti-stripping agent, thus enhancing the bonding of bitumen to fine particles. The addition of cement increases the mix stiffness through hydration. Whilst cement is not commonly used with foamed bitumen in Australia, it is used on 95% of foamed bitumen projects on New Zealand state highways. However, it is recommended that the cement content is kept under 1.5%.

The bond between soil particles with bituminous binders can be improved by the use of surface active agents or anti-stripping additives. These additives usually improve the wet strength and water absorption resistance and can be mixed with the material before the addition of the bituminous binder, or be combined with the bituminous binder before use. The proportion of such additives is usually only about 0.3 to 1.0% by mass of the bitumen.

7. Chemical Binders

7.1 General

The following categorises the mainstream chemical binders and their reaction with subgrades and pavement materials.

Synthetic polymers: PVA or PVC polymers and acrylimide copolymers bond fine particles and impart hydrophobic properties to soil. They are effective in sandy soils, lime added for clays.

Organic: Tall oil, sulphonated lignin, di-limonene may also be categorised as natural polymers. They generally require adequate material grading and plasticity and cement or lime can be added.

Ionic compounds: An electro chemical charge is imparted to clay platelets. The binders are very material dependent and are slow reacting.

Salts: Water-attracting (hydroscopic) magnesium chloride is the most common. They require moisture (humidity) to be effective. These binders require frequent reapplication following rain.

The applications of chemicals in stabilisation are either as binders or surface treatments for dust suppression on unsealed roads.

Chemical binders are generally suited to:

- surface bonding and moisture penetration resistance on unsealed road surfaces
- 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
- assisting in the dispersion of cementitious binders in high fine content materials
- reducing plastic shrinkage in cement stabilisation.

Lignin products are reported to be suitable as an anti-stripping agent in bitumen emulsion stabilisation.

Chemical binders vary significantly in composition and their effectiveness is often governed by soil plasticity and grading. The action of chemical binders is:

Surfactant: reduce surface tension (wetting agent)

Dispersant: separate fine particles from each other

Hydrophobic: repel or reduce moisture ingress

Ionic bonding: reverse the electrostatic charge on some soil platelets

Adsorption: attract atmospheric moisture to reduce dust emission

Dilatant: dispel water when compacted under vibration

Adhesion: act as a glue in bonding particles.

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

The number of products available has increased significantly over the past ten years and over the past five years some detailed performance assessments have been undertaken with particular reference to:

- unsealed roads asset management in terms of applications reducing maintenance interventions and sheeting life
- rehabilitation of sealed roads utilising their surfactant nature to achieve compaction or in conjunction with cementitious binders as a supplementary binder
- rehabilitation of sealed roads with thin granular layers as a short term treatment to increase service life rather than undertake a structural overlay or re-sheeting.

The selection of a chemical binder requires due consideration of manufacturers' technical detail and assessment of quantitative data from case histories. It is also necessary to consider such attributes as leaching, environmental contamination (particularly acids) and effectiveness on the particular soil/pavement material being considered.

7.2 Synthetic Polymer Binders

Synthetic polymers may be grouped into water soluble and water insoluble; most synthetic polymers in Australia are sold in a dry powdered format.

7.2.1 Insoluble Dry Powdered Synthetic Polymer (IDPSP)

A water insoluble dry powdered synthetic polymer is a manufactured material that is thermally bound to a very fine carrier such as fly ash, and should not be confused with dust suppressants. The fine powdered product, when mixed with hydrated lime, has the effect of flocculating and coating clay particles within the pavement material. The fly ash, which is encapsulated by the polymer, is effectively inert and does not react chemically in the stabilisation process. Its only function is to facilitate the distribution of the polymer throughout the pavement material. This polymer is used only in the powdered format and remains in a powder form during the pavement material mixing process.

Most water insoluble synthetic polymers act to preserve the dry strength of pavement materials by creating a hydrophobic soil matrix, reducing permeability and minimising water absorption into the clayey fines.

Three IDPSP blends are commercially available and spread at a rate of typically 1% to 2% by dry mass of pavement material (AustStab 2007).

- the synthetic polymer thermally bonded to a fine powder carrier (i.e. fly ash)
- a blend of 2:1 synthetic polymer-coated fly ash/ hydrated lime for medium plasticity materials (< 12)
- a blend of 1:1 synthetic polymer-coated fly ash/ hydrated lime for higher plasticity materials (12 < PI < 20).

7.2.2 Synthetic Soluble Polymers

These products are manufactured in granulated or liquid form and added to the compaction water to form a polymer chain which is an acrylimide or urethane copolymer. These products encapsulate soil particles with a thin film of polymer and, upon drying, create bonding and water insolubility is achieved.

7.2.3 Organic

These are generally obtained as a by-product of the timber pulping industry (sulphonated lignin, tall oil pitch) or citrus industry (sulphonated di-limonene). The lignin sulphonates (sodium, calcium and ammonium lignin sulphonates) and di-limonene are by-products of the ‘sulphite’ pulping process while tall oil pitch (also sometimes referred to as pine tar) is a by-product of the ‘Kraft’ pulping process.

Crude tall oil is separated from the Kraft pulping process waste liquors and then further processed for extraction of volatiles, such as rosin, esters, and fatty acids. The tall oil pitch is the residual component of this secondary process, characterised by tacky and hydrophobic properties. Tall oil pitch is usually converted into a water-based emulsion to facilitate the handling and application.

The action of tall oil pitch is by adhesion of the fine particles of the soil or pavement material, resulting in a glued matrix interlocking the larger aggregates. The hydrophobic property of the tall oil pitch reduces water permeability of soils and pavement materials.

Particle size distribution and plasticity are important factors influencing the selection of material to be stabilised with organic binders. High plastic materials with tall oil pitch have demonstrated improved cohesion and neutralised clay reactivity.

7.2.4 Ionic

These are mainly derived from sulphonated petroleum products and are highly ionic. Electro-chemical dust suppressants work by expelling adsorbed water from the soil which decreases air voids and increases compaction.

7.2.5 Salts

These chemicals are largely waste products from the salt production industry or naturally-occurring in salt lakes. Magnesium chloride forms a large component of sea water. Salts suppress dust by attracting and trapping moisture from the air, keeping the road surface moist.

When the atmospheric moisture falls below a certain level, these chemicals lose their effectiveness. Hygroscopic chlorides (sodium chloride) cease to function at below 70% relative humidity and deliquescent chlorides (calcium chloride and magnesium chloride) cease to function below 30 to 40% relative humidity, depending upon the ambient temperature.

These types of binders are not suitable for use where a bituminous spray seal or asphalt may be incorporated as the crystalline growth induces ‘eruptions’ in the seal caused by volume changes in the basecourse.

8. Effect of Binders in Stabilisation

The binders most used in road pavement stabilisation comprise cementitious, bituminous or chemical products and added material. Stabilised pavement material i.e. modified or bound can be achieved with a number of different binders or combinations of binders. An overview of the attributes associated with commonly-adopted binders is presented in Table 8.1.

Table 8.1: Application characteristics of different stabilising binders

Stabilisation binder	Stabilising action	Stabilisation effect	Applicable soil types
Cement & blended cement	Cementitious inter-particle bonds are developed. Reactions are temperature dependent.	Low binder content (<2%): decreases susceptibility to moisture changes, resulting in modified or lightly bound materials. High binder content: increases modulus and tensile strength significantly, resulting in bound materials.	Not limited apart from deleterious components (organics, sulphates, etc. which retard cement reactions). Suitable for granular soils but inefficient in predominantly one-sized materials and heavy clays.
Lime (including hydrated lime and quicklime)	Agglomerates fine clay particles into coarse, friable particles. Secondary inter-particle bonding occurs if excess lime available. Reactions are temperature dependent.	Improves handling properties of cohesive materials. Low binder content (<2%): decreases susceptibility to moisture changes, improves strength resulting in modified or lightly bound materials. High binder content: increases modulus and tensile strength, resulting in bound materials.	Suitable for cohesive soils. Requires clay components in the soil that will react with lime. Organic materials will retard reactions.
Cementitious	Lime and pozzolans modify particle size distribution and develop cementitious bonds. Reactions are temperature dependent.	Generally similar to cement but rate of gain of strength similar to lime. Also improves workability. Generally reduces shrinkage cracking problems.	As for cement stabilisation. Can be used where soils are not reactive to lime.
Bitumen, either foamed or emulsion	Agglomeration of fine particles.	Decreases permeability and improves cohesive strength. Decreases moisture sensitivity by coating fines.	Applicable to granular materials with low cohesion and low plasticity.
Granular material	Mixing two or more materials to achieve planned particle size distribution.	Some changes to soil strength, permeability, volume stability and compactability. Materials remain granular.	Poorly graded soils, granular soils with a deficiency in some size(s) of the particle size distribution.
Chemicals	Agglomeration of fine particles and/or chemical bonding (see trade literature).	Typically increased dry strength, changes in permeability and volume stability.	Typically poorly-graded soils and gravels.

9. Safety in Handling and Using Binders

It is essential (and a legal requirement) that all binders be supplied with a Materials Safety Data Sheet (MSDS). The following website provides access to over 250,000 products:

www.msds.com.au

The pertinent features of safety with particular binders are detailed in Table 9.1.

Table 9.1: General safety considerations

Health risk	Description
Dust	A danger to inhalation by workers and a potential hazard in built-up residential areas on windy days as well as loss of binder in terms of desired application rate. The use or application process of fine powder binders such as cement, lime, slag or fly ash combinations and dry powder polymers needs to be considered according to the weather conditions.
Burning	A number of chemical binders, e.g. ligno sulphonates and their derivatives, are highly concentrated sulphuric acid-based which in their undiluted form are a danger in handling, particularly when discharging to a water tanker. Breathing masks are always recommended. Quicklime will burn on contact with skin and therefore in addition to workers' safety, consideration needs to be taken in residential areas, pedestrians, etc.
Toxic fumes	Generally associated with chemical binders; breathing equipment should be used in all circumstances.
Dermatitis	Handling dry powders such as cement or lime will cause dermatitis and therefore gloves should be worn.
Heat	Slaking lime with water produces excessive heat and steam discharge.

For complete safety guidelines associated with foamed bitumen stabilisation refer to Section 15 of Austroads (2008).

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Austroads' **Guide to Pavement Technology Part 4L: Stabilising Binders** discusses the various types of stabilising binders used in road construction; lime, cement, cementitious pozzolans, bitumen, chemical and synthetic polymers. It examines their properties, manufacture, chemical reactions during the stabilisation process and safety considerations associated with their use.

Guide to Pavement Technology Part 4L

Austroads

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