# Cementitious Binder Options

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**Summary** Road insitu stabilisation has been used for road pavements in Australia since the 1950's as a low-cost method of improving rural and urban roads. While the principles behind the process of stabilisation remain similar to those employed at its introduction, major advances have been made in construction equipment and the development of cementitious binders. This paper will examine binder constituents and the mechanisms through which they improve pavement materials, and considerations that must be made by the pavement engineer when examining binder options.

## 1 TERMINOLOGY

The Australian Standards issued a glossary of terms for road and traffic engineering in 1986 (Ref.1) and unfortunately, many of the terms are not applicable for road stabilisation. To adjust for this limitation in the Standard, AustStab produced in 1996 a guideline on terms (Ref.2). These guidelines provide a satisfactory reference point for this paper to define specific terms, as noted below:

| Term | Definition |
|---|---|
| additive | A substance added to a material for the purpose of improving its properties. |
| binder | A material used for the purpose of binding particles together as a coherent mass. |
| Ground Blast Furnace Slag (GBFS) | A ground non-metallic product, consisting essentially of silicates and alumino silicates of lime, developed simultaneously with iron in a blast furnace. |
| bound material | Granular material to which cement, bitumen or similar binders are added to produce structural stiffness. |
| Fly Ash (FA) | A fine powder of pozzolanic material extracted from the flue gases of a boiler fired with pulverised coal. |
| gap graded material | Graded material in which one or more of the intermediate sizes are absent. |
| graded material | Material having a wide and substantially continuous distribution of sizes from coarse to fine, the largest size being several times larger than the smallest size. |
| modification | The improvement of the properties of a material by the addition of small quantities of an additive by the stabilisation process. |
| pozzolan | A siliceous or alumino siliceous material which in itself possesses little or no cementitious value but which in finely divided form may be mixed with lime or portland cement to form a cementitious material. |
| recycling | The reuse of pavement material by insitu or plant mixing, with or without the addition of new material components. |
| rehabilitation | The restoration (e.g. stabilisation) of a distressed pavement so that it may be expected to function at a satisfactory level of serviceability for a further design period. |
| stabilised soil | A material which has been modified to improve or maintain its load carrying capacity. Modification may be by the addition of other natural materials such as sand, loam or clay or of manufactured materials such as cement, lime, and bitumen. |

The word stabilisation may be printed as "stabilization" and the Australian trend over the last 20 years has been to use the "s" rather than "z". This is an important issue when searching the Internet with one of the various search engines as the number of sites found varies according to the spelling of stabilisation.

## 2 INTRODUCTION

Soil stabilisation is a construction procedure where natural or manufactured additives or binders are used to improve the properties of pavement materials. This process has been widely used in Australia since the 1950s (Ref.3).

These additives or binders can produce mechanical (e.g. the addition of fines to a coarse material to improve its grading) or chemical (e.g. lime, cement etc) where the reaction created either binds or improves the engineering properties of the soil.

This paper only discusses chemical stabilisation using cementitious binders. Cementitious binders are those manufactured materials, such as lime and Portland cement, and processed by-products of manufacturing and power generation, such as granulated blast-furnace slag and fly ash.

## 3 BINDERS

### 3.1 General

The most commonly employed road recycling binders are:

- ❑ GP and GB Cement
- ❑ Lime
- ❑ Blended products

The use of a particular binder is generally related to the soil type. For instance, a reactive clay would be most suitable with a lime binder. The properties of various binder types are noted in the following sections.

### 3.2 Lime

Lime used in stabilisation is the product of calcining limestone. Lime is generally referred to either calcium oxide (quicklime) or calcium hydroxide (hydrated lime - result after quicklime + water reaction). Lime is most commonly used as a modifier of clay soils and in some cases it has been used successfully for the stabilisation of low-clay content granular soils (e.g. P <10).

Lime stabilisation is a two stage process consisting of:

1 Immediate modification of the soil via agglomeration of the fine clay particles into coarse, friable particles through an ion exchange.
2 Secondary cementing action over time as the remaining free lime (through dispersion via pore water) reacts with either silica or alumina in the soil (or with other added pozzolanic products) to form calcium aluminates or silicates.

These two reactions result in a treated clay soil with decreased plasticity, lower affinity for water (greater volumetric stability and lower permeability), increased cohesion and strength (shear, compressive and tensile) and subsequently greater durability.

While its effectiveness is vastly reduced with low to non-cohesive soils, lime is often used as a constituent in blends to react with clay fines in the soil and to act as a catalyst for the reactions of other additives in the blend, such as flyash or slag.

## 3.3 Portland Cement

Through the mixing of calcium carbonate, alumina, iron oxide and silica, and the calcining and sintering of this mixture Portland cement is formed (Ref.4). The resulting product hydrates in the presence of water to form hydrated silicates and aluminates and calcium hydroxide. When cement, or technically called General Purpose (GP) cement, is used in stabilisation a “weak” concrete (via inter particle bonding) with the treated soil is formed.

With soils containing some clay the calcium hydroxide produced will react to modify or cement (secondary cementation) the clay particles.

Cement has a two stage reaction process similar to that of lime. The first commences within minutes of mixing with water (hydration) and the secondary cementation occurs as the free-lime is diffused through the soil matrix.

In the last few years General Blend (GB) cement[1] has gain more use in insitu stabilisation as it allows greater working time for contractors. Increasing the working time is important for stabilisation projects where the pavement depth exceeds 250 mm.

## 3.4 Granulated Ground Blast Furnace Slag (GGBFS)

A pozzolanic by-product of iron manufacturing, GGBFS[2] consists of coarse, rough textured particles which are composed of approx. 93-99% glass. These particles are unstable and when mixed with water and in the presence of an activator will react rapidly to form stable crystals of calcium-alumina-silica hydrate (products similar to those produced from the hydration of cement).

This process can be initiated without an activator although the reaction is extremely slow and is not yet considered suitable for stabilisation (also refer to reference 5).

The activator must form an alkaline solution in water and thus lime is ideally suited. Lime (calcium hydroxide) can be obtained by either the addition of lime in the slag or from the hydration process of GP cement. It is therefore common for GGBFS to be blended with either lime or GP cement clinker.

[1] A GB cement is defined in AS3972 as a cement containing portland cement and a quantity comprising of one or both of the following (a) >5% of fly ash or GGBFS, or both (b) up to 10% silica fume.
[2] Today, this type of slag is only used in insitu stabilisation.

### 3.5 Fly Ash

Fly ash is produced when ground coal is burnt in the electricity generation process. It is a very fine grained pozzolanic material (silica & alumina oxides) and in the presence of both an activator and water will produce cementitious compounds (similar to those produced from the pozzolanic reaction of slag).

## 4 USE OF BINDERS IN AUSTRALIA

Prior to the 1990s binders used for road stabilisation could be categorised into two distinct groups, that is lime or cement. Today one could consider the following categories of soil binders:

- ❑ GP cement to AS3972 (Ref.4)
- ❑ GB cement to AS3972 (Ref.4)
- ❑ Cementitious blends, for binders consisting of combinations of flyash, GP cement, ground blast furnace slag and lime, and including triple and quartenary blends
- ❑ Lime
- ❑ Cement/bitumen blends
- ❑ Gypsum

While the theoretical strength, permeability / moisture and durability characteristics of cement treated pavement are obvious, as pavement standards and cost analysis of road networks became more detailed and environmental considerations gained increasing importance, pavements treated solely with cement were identified as having some limitations:

- ❑ low working times (typically less than 2 hours) hindered economical output and satisfactory compaction, ride and level control,
- ❑ too high strength often resulted in extensive shrinkage cracking with resultant declines in durability, and
- ❑ cost premium for manufactured cement in comparison to other similarly performing 'by-products'.

As a result blended binders consisting of flyash and blast furnace slag with cement and lime began to be produced by cement manufacturers. With the blending facilities available today there is no limit to the proportioning of the various additives[3]. At this stage up to four different materials are generally blended in any ratio from one distribution facility.

Generally the price of the blended binder will reduce in cost as the proportion of cement decreases and this is more so in NSW. However, the cost will be related to the proximity of the material source and blending plant to the stabilising site.

The variety of blends have flourished when the deep-lift process (Ref.6) became widely accepted in NSW. The research and development of insitu stabilisation up to 400-mm in thickness was spearheaded by Geoff Youdale in the RTA, NSW (Ref.7). There are some 400 or more kilometers now stabilised in NSW and many of these pavements are being regularly monitored.

[3] Queensland Cement Limited offer Dial-a-Blend™ and Rocla offer any blend ratio to its customers so they may provide a range of product solutions.

Blends containing fly ash and GGBFS, and containing cement when complying with AS 3972 -1991 are classified as type GB cements. Generally GB cements provide 1 to 2 hours additional working time over GP cement.

In NSW a GP Cement and Fly Ash Blend is popular with local Councils carrying road stabilisation. The proportion of the blend can be varied although supplier standards exist (e.g. 70% GP cement/30% fly ash; or 75/25).

The fly ash relies on free lime produced from the cement hydration as an activator, after which any further free lime may react with reactive elements in the soil to produce more cementitious products.

Blends utilising cement have rapid strength gains within the first 24 hours (initial cementation) and there is ongoing strength gain proceeding slowly over time.

Subject to proximity of the site to the blending plant and source of fly ash this blend is more economic than straight cement. It has a slightly longer working time and strength characteristics over time similar to that of cement.

The use of slag (GGBFS) and GP cement blends are well suited to road pavements where a short working time is not critical to the project. Being a hydraulic binder slag does not require lime to initiate a reaction. The free-lime from the hydration of the cement, if not used by the slag may be taken up in reactions with the soil. The cost of these blends, consisting of slag and cement, vary according to the locality of the project from the source of the slag.

Slag (GGBFS) and lime blends, and flyash and lime blends are being used where fly ash and slag are relatively cheap compared to GP cement. As previously noted lime is an ideal activator for pozzolanic reactions (i.e. the lime content is typically a minimum of 12 to 15% of the blend). If the soil to be treated contains amounts of clay fines a blend using greater than 15% may be employed. In these cases the aim is to ensure that there is sufficient lime in the blend for both the activation of the slag or fly ash and the modification of the clay fines. Should insufficient lime be included in the blend the overall performance of the material will be reduced.

Where gravels have had particularly high clay contents, blends of up to a 50/50 slag and lime have been used. The blends incorporating lime (and not containing cement) have slower rates of reaction and therefore, a slower strength gain.

Blends utilising fly ash, slag and lime have working times typically up to 4 times that of straight cement with working times of up to 48 hours being available.

Blended binders containing fly ash, slag and cement or lime are also available. The main benefits of these triple blends is the greatly increased working times (up to 8 hours) and reduced cost. In addition to the increased working times ,these triple blend binders are also less susceptible to rapid reductions in strength gain as a result of compaction delays.

The mechanisms through which they reduce the deficiencies within a soil are a combination of those detailed above. While strengths gained with the triple blended binders are below that for recycling using GP cement they are more than adequate for general pavement designs.

The flexibility of the component proportions in these triple blends also allows for a more specifically suited binder to each soil type (after sufficient laboratory testing).

# 5 USE OF STABILISATION IN WA ROADS

## 5.1 Main Roads Western Australia (MRWA)

The use of cementitious binders by the MRWA in regional areas is chosen for recycling pavements and floodway stabilisation principally on costs. However, other important factors driving the decision to use these binders are:

- proven track record as an effective binder for stabilisation work,
- most soils around WA are suitable for cement stabilisation, and
- they reduce moisture sensitivity of some gravel base courses, in addition to increasing strength.

Other secondary factors include limited access in some regions to good quality road construction materials and the large haulage distances between source of construction material and work site.

Lime has limited applications as the soil is typically granular. In the South West Region there is some concern that lime is not an effective stabilising binder for the type of clayey soil found and therefore, GP cement is used.

The major benefits of the cement type binders (i.e. GP, LH, GB) are that they are cost effective, proven binders suitable for the majority of soils in the State and by contractors who have the necessary specialised equipment and experience.

## 5.2 Local Government

Local Government road managers are currently limited users of insitu stabilisation for road maintenance or rehabilitation. The metropolitan councils who undertake road stabilisation note that cementitious binders have a proven track record. The preference for lime or lime/slag blends over GP cement is principally based on soil type (clayey versus sandy) and lime has a longer working time.

Some Councils in WA note that insitu stabilisation is not used for roadworks due to:

1. Availability of good quality, relatively cheap road construction material, suggesting stabilisation as a relatively costly option at the moment (Ref.8).
2. Low traffic volumes on most LG roads, with any maintenance work concentrating on the asphalt wearing surface, rather than distressed basecourse or subbase.
3. High CBR subgrades, particularly in most areas of Perth, which may lessen the benefits of significantly reducing pavement reconstruction costs by using cementitious binders.
4. General reluctance on the part of local government to change their maintenance operations.

The first two issues appear to be odds with stabilisation as local government departments in NSW and Queensland have successfully used insitu stabilisation with existing pavement materials in low volume roads regardless of the CBR values of the existing pavement.

The limiting supply of good sound pavement material for rehabilitation work in the eastern States is likely to extend to the WA regions along with increasing charges for tipping existing pavement materials (Ref.9). These two factors alone may drive changes to rehabilitation practices at State and Local Government levels.

## 6 CONCLUSIONS

Many insitu stabilisation road projects have been successfully carried out in WA using the cementitious binders described in this paper. The use of GP cement has declined as the benefits of using GB cement have been identified and used successfully.

The cost of the binder should not always be the main decision criteria for insitu stabilisation. If long working time is essential for the job site additional binder costs may only represent an 10% increase in project costs and the net consequence is a better opportunity for the contractor to achieve the desired ride quality.

The strong natural subgrade material in regions of Perth provide some limitation to the use of insitu stabilisation but as traffic volumes increase and the availability of good pavement materials becomes less certain, the use of stabilised subbase will be required to meet higher performance levels.

## 7 REFERENCES


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**Acknowledgments**

I would like to thank Stuart Torpy, Boral Road Services and Pat Aguero, Cement and Concrete Association of Australia for providing some of the text for this paper.


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