SELECTION OF ADDITIVES FOR STABILISATION AND RECYCLING OF ROAD PAVEMENTS

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1 INTRODUCTION

This paper is concerned with the application of stabilisation additives developed in recent years. An earlier paper (Wilmot 1989) discussed the traditional additives while predicting the development of a much wider range of products. These products are now commercially available and while widely used, a considerable amount of confusion exists in selecting the most suitable additive for any particular application.

Insitu stabilisation has been used as a method of road construction and recycling in Australia since the 1950's. This paper has been compiled as a result of some 25 years of field experience in stabilisation from the late 1960's. During this time there has been a steady increase in the use of insitu stabilisation. The great majority of the early work used Type A, now Type GP cement (Australian Standard, AS 3972, 1991) and to a lesser extent, blended products such as 75% Portland cement and 25% flyash, now GB cement and some bitumen systems such as foamed bitumen or impact bitumen. Hydrated lime stabilisation was widely used to upgrade local gravels but had limited use in total pavement recycling.

In the late 1980's, blended cements that would now be defined as GB cement were widely used for cement type stabilisation in New South Wales, South Australia and Queensland. There are also a number of blended products which fall outside the specification for GB cement. These products contain large percentages of slag or flyash blended with hydrated lime or cement. They are characterised by generally giving a significantly longer working period while obtaining a similar longterm strength as GB products. Design engineers now have a much wider range of additives from which to choose for pavement stabilisation and recycling.

2 CEMENTITIOUS BLENDS

2.1 Designer Blends

Blends commonly consist of a mixture of ground granulated blast furnace slag (slag) or classified flyash (flyash) blended with hydrated lime or cement. The hydrated lime, or free lime in the cement, acts as an activator for the slag and initiates a pozzolanic reaction in the flyash. The resultant 'cement' typically has an initial set or working time of 4 to 8 hours for blends containing GP cement or up to 2 days for blends of lime with slag or flyash.

The proportions of flyash, slag, hydrated lime and cement may all be varied to provide a blend most applicable to a specific job condition; in particular, climate, soil type, construction program and strength requirements, hence leading to the term designer blends.

The effectiveness of the blended products are dependent upon the quality of the ingredients, and since these should comply with the relevant Australian standard, a certain basic quality can be assured. It is vitally important that these blended products be blended with properly designed blending plants and not roughly proportioned into truckloads or other crude methods of blending. An important factor not fully shown up in the Standards is the fineness of the individual materials. This factor appears on Roads & Traffic Authority (NSW) specification sheets, where the fineness of the material is to be specified (RTA Specification R40, 1993). The finer the material is, the more chance it has of being intimately mixed with the host material and a better reaction results. However, as the material becomes finer, it becomes far more difficult to handle through the spreading equipment. While most equipment has been developed for handling GP and GB cements, the extreme fineness of some of the blends containing finely ground slag, flyash and some of the fine hydrated limes have required modification and careful use of spreading equipment. The finer material has required the development of spreaders with closer tolerances on their rotor design and improved dust control equipment. In many cases, spreading needs to be followed by a fine water spray to hold the material in place until mixing.

2.2 Application Of Blends

While the blends are applicable to almost any application where GP or GB cement would have been used, the development of deeper mixing for the recycling of highways has been greatly assisted by slower setting cements.

In 1992, the RTA (NSW) conducted trials to investigate the validity of recycling highways by insitu stabilisation to depths of 300 to 400 mm in a single lift (RTA 1992). The industry responded rapidly to this challenge and at February 1994 there are over 100 kilometres of highway reconstructed by insitu stabilisation to depths of between 300 mm and 375 mm. These deeper depths require considerable compacted effort. If GP or GB cement is used, this compaction must be achieved within 3 hours. Using blends with a longer set time provides more confidence in achieving full compaction. As the cementing process proceeds, compaction becomes more and more difficult.

The action of the cementitious stabilising agent with the pavement material is a progressive process which commences immediately mixing is undertaken. The process establishes chemical bonds which provide the material with an ultimate strength but initially acts to reduce compactibility.   The ability to design a delay to this process not only assists in obtaining compaction but also allows time for rerolling should it be necessary.

2.3 Working Period And LDL

Each mixture has its characteristic working period. This has previously been thought of as approximately equal to the time of the initial set of the cement. The RTA specification R40 now relates this working period to a newly defined term the 'laboratory density loss period'(LDL). This more closely predicts the performance of the mix to a laboratory test.

The LDL value is determined by laboratory investigation and is defined as the time period which commences at wet mixing and finishes when tests verify that the achievable maximum dry density (standard compaction) has dropped by more than two percentage points relative to the maximum dry density (standard compaction) achieved when compaction immediately followed wet mixing at laboratory optimum moisture content.

It should be noted that this workability is a property of the mixture of the stabilisation additive and the host material whereas 'initial set' is a property of the cement not of the mix.

The LDL provides a measurement of the time before significant resistance to compactibility is developed. From this measurement of LDL a 'working time' can be established. This working time refers to the time between 'wet' mixing in the field and the completion of primary compaction. Considerably more work needs to be done in establishing LDL values and relating these to field working times.

2.4 Effects On Roughness

Finishing of recycled pavements using cement stabilisation has always required a great deal of skill. Grader operators must work with the insitu material which often includes large stone and they must be careful to cut to waste and not create a false pavement. All of this must be done before the time the cement establishes too much strength. While this produces an acceptable rideability for most roads, more time is normally required to achieve satisfactory roughness counts for highway construction. Current RTA specifications call for a maximum roughness count of 50 counts per kilometre over any 200 metre length. In contractual arrangements severe penalties occur for roughnesses over this count. Recent work carried out using blends of slag and hydrated lime on the Pacific Highway have achieved roughness counts of between 30 and 50 while earlier trials carried out using cement based blends, with a 3 hour set-time, were only able to achieve roughness counts in the order of 80 to 100.

3 POLYMERIC STABILISERS

While the concepts of products such as Polyroad and Flexpave appear to have been originally developed in Europe, the subsequent Australian developments have produced an additive of superior quality and at a viable cost to the road builder.

Polymeric stabilisers are available as a powder of similar appearance to finely ground cement. Products commonly consist of a mixture of polymers thermally bound to a carrier such as flyash. Although polymer treated soils appear to 'set up', the polymers are not strictly binders and the pavement remains truly flexible.

To gain full benefit from the polymer, it must be well distributed through the host material. The polymer attaches itself to the fines and acts to protect those fines from the action of water. Polymer treatment greatly reduces capillary rise, increases soaked CBR values, increases wet strength and reduces permeability with consequent reduction in pore pressure.

4 STABILISATION MIX DESIGN

4.1 Design

There are two design items to specify. Firstly, what additive to use and secondly, how much of it. In the past, it has been sufficient to specify whether the additive should be hydrated lime, polymer, bitumen, or cement. Now rather than cement, the specification would read cementitious material or designer blend. By blending these materials it has been possible to extend the areas in which cement could have been used into those previously defined as hydrated lime and cement type work. It is now possible to increase the hydrated lime content in the blend, so as to get a two fold reaction, firstly from the hydrated lime treatment of the soil and secondly, from the following cementitious reaction.

Table 1 provides a very broad guide as to where to start in selecting the additive most suitable to the host material. From there it is necessary to go into laboratory design to determine the percentage of the additive and in the case of the cementitious blend, the actual specification for the blend. As the general discussion on design for the conventional products has been covered in previous technical papers, it is intended here to only cover the recent developments of designer blends and a brief section on polymeric stabilisers.

TABLE 1
SUITABILITY OF ADDITIVE TO SOIL TYPE

	CRUSHED ROCK	WELL GRADED GRAVEL	SILTY/ CLAYEY GRAVEL	* SAND	SANDY/ SILTY CLAYS	HEAVY CLAYS
CEMENT	A	A	A	B	B	N
BLENDS CEMENTITIO US	A	A	A	A	A	B
HYDRATED LIME	B	B	A	N	B	A
HYDRATED LIME + CEMENT	N	N	B	N	B	A
POLYMERIC	B	A	A	B	A	B
BITUMEN	A	A	B	B	N	N

Usually very suitable A
Usually satisfactory B
Usually not suitable N

*Depends upon grading. Single size sands require higher additive contents

4.2 Hydrated Lime Based Blends

There are an endless number of permutations and combinations of materials available to design the blend. The choice to use either slag or flyash may often be determined by availability or commercial consideration. In general slag will normally provide a slightly stronger and faster responding blend than flyash. The final solution may be a triple blend (Bullen 91), that is a mixture of slag, flyash and either hydrated lime or cement and some blends have even incorporated all four products.

Slag and flyash both require in the order of 8% to 10% of hydrated lime to fully activate the reaction. To ensure that all the flyash and slag is fully reacted, it is normal for blends to contain a minimum of 12% to 15% hydrated lime. Further hydrated lime in the blend is then available to stabilise the clay fines present in the host material. This leads to the first guideline for the design of the blend, in that if the material contains a high proportion of clay fines, the hydrated lime content should be increased. Typically, gravels containing relatively high clay content have been successfully stabilised using a 50/50 blend of slag and hydrated lime. Alternatively, a triple blend containing 50% hydrated lime, 30% flyash and 20% slag.

Appendix 1 shows an example of the effect of different hydrated lime percentages in the mix. The curve (fig 1) illustrates that there is an optimum blend. This occurs where the maximum amount of slag (or flyash) is available to react with the free hydrated lime after some hydrated lime has been used in the modification of the clay fines. It follows that good quality non-plastic materials will respond best with a mix such as 85/15 (slag/hydrated lime) whereas the material in the example below (a clayey sand gravel mix) responded best at 60/40.

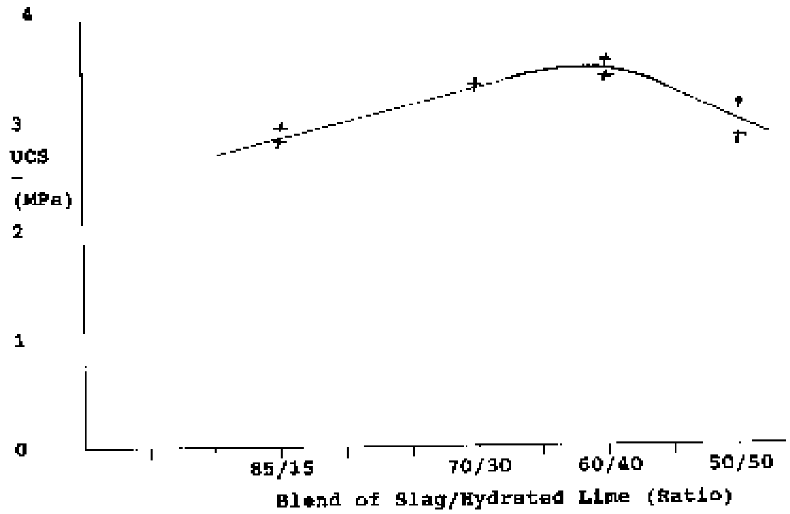


Fig. 1

FIGURE 1 COMPRESSIVE STRENGTH VERSE HYDRATED LIME CONTENT IN BINDER

Generally, blends containing only slag and/or flyash and hydrated lime have working times of 30 to 48 hours.

4.3 Cement Based Blends

Cement in the blend will greatly reduce the working time. Mixtures of 50% cement to 50% slag would probably have working times in the order of 3 hours, not much longer than a normal GB cement. To extend this working time, a triple blend of slag flyash with small proportions of cement will give working times in the order of 4 to 8 hours. Some manufacturers are also currently working on standard blends which will give extended set times in the order of 8 hours.

4.4 Quantity Of Cementitious Additive

The dosage rate will be determined by the type of pavement layer required. Generally, these are categorised as modified, lightly bound or heavily bound. There are no distinct boundaries between these types. General descriptions are:

Modified	The gravel properties are modified and the pavement does not depend upon any binding being developed. Typical dosage 1% to 2% by wt.
Lightly Bound	Some binding occurs and a stiffness in the order of 3000 MPa may be used for design purposes. Typical dosage 2%-4% by wt. UCS target 1.7 MPa at seven days at ambient temperature for cement and 2.0 MPa at 28 days at ambient temperature for blends.
Heavily Bound	These pavements are most applicable to layers of over 250 mm thick and a stiffness of 4000-5000 MPa may be used for design. Indicative UCS results at 28 day at ambient temperature would be over 2 MPa.

While UCS has little relevance to pavement design, it is a relatively inexpensive indication of the effectiveness of various binders in the host material.

Traditionally, most design was based on 7 day strength either at ambient temperature for most recycling work and accelerated 7 day results by some Road Authorities. The author believes that accelerated testing may give misleading results, particularly where the heat may alter the properties of the material.

One of the difficulties of comparing results established over 20 years on GP and GB mixtures is that the new blends give little or no significant result at 7 days at ambient temperature, the test method most commonly used to date. Consequently, it has been necessary to use 7 day accelerated or 28 day at ambient temperature. Current indications are that in order to compare different blends and achieve relatively consistent results, it is advisable to use 28 day at ambient temperature for slow setting blended binders. However, in many cases sufficient time is not available to assess 28 day results and it is necessary to consider 7 day accelerated testing. This problem may lessen as a data base on material performance is established by researchers and practitioners.

The RTA Guidelines further comment that

The curing of stabilised materials for UCS testing with slow setting hydraulic binders has been observed to lead to occasional inconsistent results. Accordingly a thorough mix design requires approximately 4 pairs of UCS tests per kilometre (10,000 m^2 say). Outlier results can then be eliminated and the mean result of at least 5 result s can be adopted to represent the response of the pavement to stabilisation meeting a set mix design.

4.5 Erodibility

There is a school of thought that dictates that all mixes should contain 5% by wt of additive in order to achieve a satisfactory durability and protection against erodibility. This was further encouraged after the ALF trials at Beerburrum Queensland (Kadar 1987) indicated failure of cement treated base at the layer interface. The author believes that this is not at all relevant to insitu stabilised layers, particularly deep single lifts where eroding of the pavement is unlikely to occur.

4.6 Polymeric Stabilisers

Polymer modified soils and gravels are becoming a viable option in both road construction and pavement recycling. The correct polymers when distributed through the soil act to repel the moisture from the fines in the host material. By repelling this moisture, characteristics of the dry material can be maintained through soaked conditions. They are most responsive in soils or gravels containing over 10% silt or clay fines (Albury and Marshall 1992). However, they have also been found to be particularly useful in other granular materials and each material should be investigated individually to assess the benefits of the polymer modification.

Unlike the cementitious blends, polymers do not significantly increase the dry strength of the soil. Hence UCS testing is not considered appropriate for investigating the benefits of polymer stabilisation. Polymer modified material will typically have a flexural modulus in the same order as the dry natural material. However, by keeping the water out of the pavement, it achieves greatly increased soaked CBR values and some increase in soaked UCS strengths. One of the most significant improvements is the reduction in pore pressure experienced in the polymer modified pavement.

4.7 Design Of Polymer Mix

As the polymer treatment is a physical treatment of the soil, a standard dose rate is normally applied. To ascertain the suitability of any particular host material, the most rapid test is to carry out a capillary rise observation of both the natural and the polymer modified material. This can be easily carried out by compacting a mould of each using standard compaction and observing the sample sitting in a tray containing approximately 30 ml of water. Successful treatment of the soil will show minimum or nil capillary rise, whereas the untreated sample will probably show considerable capillary rise and possibly a total collapse of the material. In having ascertained from this test that the material is conducive to polymer modification, further testing of the modified material may be carried out to determine the new material characteristics such as soaked CBR and resilient moduli.

The pavement should be designed as a normal flexible pavement using the improved values for CBR and/or resilient moduli achieved for the polymer modified soil.

5 CONSTRUCTION CONSIDERATIONS

5.1 General

Successful stabilisation using any additive requires the use of purpose built spreading and mixing equipment. The spreaders should be enclosed protecting the additive from the weather and have accurate, variable distribution mechanism. Most modern units now have an on-board weighing system to record the amount of additive spread. Mixers should be purpose built for recycling and stabilising. The mixing should not be attempted with other earthmoving or paving equipment.

5.2 Bound Pavement

Further to laboratory assessments, to achieve specific design requirements, consideration must also be given to the capabilities and methods of the construction. Where compaction is relatively easily achieved and traffic is to use the pavement as soon as possible, then the choice would probably be a GB cement. Where further time is available for grading, although the traffic may use the pavement, the ability is there to regrade the following day and where compaction depths are greater and more difficulty will be experienced in achieving full compaction, one of the slow setting cementitious blends should be used. There are various intermediate degrees which can be achieved with these blends and any set time between 3 hours and 48 hours can be designed into the blend.

5.3 Slurry Addition

Cementitious blends may be made into slurries for addition to the pavement this avoids the handling of the powdered material and the placement of the powder onto the roadway. Before slurry addition can be used it is necessary to check the binder/water ratio that can be achieved for the specified binder and then check the moisture content that is to be added to the host material, see eqn (1) .

For example:

Slurry consisting of binder:water at 70:30
Required binder content - 4% by wt of dry soil

Hence amount of water being added -

$$\text{Water addition} = 4 \times \frac{30}{70} = 1.7\% \qquad (1)$$

Under the conditions the minimum amount of water that can be added is 1.7% by wt of dry soil so the insitu moisture content must be at least 1.7% below that required for compaction.

Slurry addition can be a most useful option where insitu conditions are sufficiently dry of optimum.

5.4 Flexible Pavement

Where it is required to achieve a fully flexible pavement, the use of a cementitious material would be limited to very low percentages so as to merely modify the host material. Polymeric stabilisers will provide better waterproofing and reduction of pore pressure in the pavement thereby improving the characteristics of the host material but retaining a fully flexible pavement layer.

For polymeric stabilisers, it is important that the additive is well blended throughout the host material as it is usually a relatively small amount of additive and yet it needs to access all the fines in the material. The total construction is somewhat easier in that there are no time restraints on the compaction and the material may be remixed, recompacted or regraded at any time.

For the polymer to be fully reactive the pavement needs to cure for a period before the water resistance is fully active. This typically takes 2 to 3 days. The polymer is extremely useful in areas of high water table or flood prone areas, but the construction is best carried out during a dry period so that this curing may occur at or below optimum moisture content.

6 CONCLUSION

The development of new additives and improvements to recycling equipment over recent years has increased the scope of stabilisation to pavements of greater depth and incorporating a greater range of possible soils.

Blends of slag, hydrated lime, flyash and cement are useful for achieving maximum performance from a large range of pavement materials.

Further work needs to be done in correlating 7 day and 28 day strengths with field performance and between LDL values and field working time. The applicability of 7 day accelerated tests to blends must also be established.

Laboratory testing needs to be carried out to ascertain the optimum additive and dosage for any particular environment and material.

Polymeric stabilisers may be used to protect a fully flexible pavement from water ingress.

Most importantly these new additives are available as an extension to the conventional hydrated lime and cement stabilisation successfully used for over 40 years. There is no need to alter any currently successful programs using conventional additives unless better economics or work practices can be established.

APPENDIX 1

Example of determination of slag/hydrated lime additive for highway recycling project.

Material sampled from existing pavement to depth of 350 mm as described in the profile.

Pavement Depth 350 mm

Pavement Profile

0 mm ____________________________

Clayey silty sand some gravel
150 mm __________________________

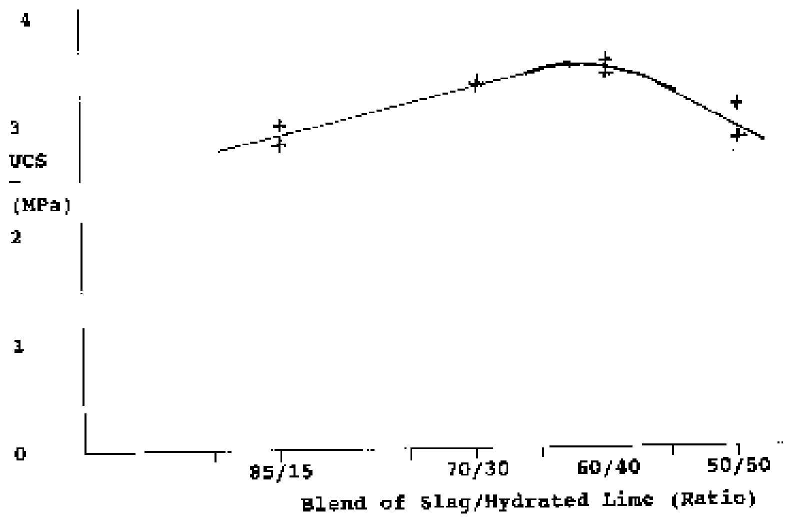
Clayey sandy gravel medium plasticity
210 mm ___________________________

Clayey sand high plasticity
350 mm ___________________________

U.C.S. Results

- 7 day accelerated cure
- 5% binder by mass

Additive Slag/Hydrated Lime	85/15	70/30	60/40	50/50
U.C.S. cyl 1	2.80	3.30	3.40	2.80
cyl 2	2.90	3.35	3.50	3.10



COMPRESSIVE STRENGTH VERSE HYDRATED LIME CONTENT IN BINDER

REFERENCES

ALBURY, D.; MARSHALL, G. (1992) Investigation of Strength and Grain Size of Properties of Gravelly Soils Stabilised with Flexpave[TM]

AUSTRALASIAN SLAG ASSOCIATION (1990) A Guide to the Use of Slag in Roads

BULLEN, F.; SUCIU, C. (1991) Maximising Aggregate Sourced by Use of Triple-Blend Cements in Stabilised Pavements Proc. 5th National Local Government Engineering Conference

HODGKINSON, J.R.; MATTHEWS, S.C. (1992) The Role of Pavement Recycling in the Efficient Maintenance of Australia's Ageing Road System Proc. 16th ARRB Conference

KADAR, P; (1987) Accelerated Full Scale Testing of Thin CTB Pavements. Beerburrum 1986-1987 ARRB Internal Report ARI 441-1

ROADS AND TRAFFIC AUTHORITY NSW (1992). Proceedings of the Workshop on In-situ Recycling of Pavements using Cementitious Binders

__________________ (1993a). Draft Specification R40 Insitu Recycling of Granular Pavements by Deep Lift Cementitious Stabilisation. Proceedings of the Workshop on Deep-lift Recycling of Granular Pavements. Technology Development Branch 1993.

ROADS AND TRAFFIC AUTHORITY NSW; STATEWIDE ROADS TECHNICAL MANAGEMENT (1993b). Guidelines for Recycling Road Pavements by Deep-Lift Cementitious Stabilisation

STANDARDS AUSTRALIA (1991) Australian Standard AS3972 Portland and Blended Cements

WILMOT, T.D. (1989). Selection of Stabilising Agents for Construction and Rehabilitation of Council Roads Proc. 5th National Local Government Engineering Conf. pp. 28-32