

EVALUATION OF STABILISED MARGINAL PAVEMENT MATERIALS USING ESTABLISHED AND NEWLY DEVELOPED CEMENTITIOUS BINDERS.

Maurice Serruto

Pavement Engineer

Blue Circle Southern Cement Ltd

Lucas Pardo

Section Manager

Chadwick Geotechnical Testing Pty Ltd

ABSTRACT

This paper will present the findings of various research programs and laboratory tests on the effects of slow-setting cementitious stabilisation binders on marginal pavement materials. It will present the VicRoads evaluation of the slow-setting binder developed by Blue Circle Southern Cement, Alkali-Activated Slag (commercially known as "Roadment"). The information presented includes research work performed by a wide range of organisations, including private industry, state road authorities and local government. An overview of the need for and the development of these slow-setting binders will also be discussed. The conclusion will summarise the adverse effects of delays to compaction on materials stabilised with GP and GB cements and the advantage that slow-setting binders have when extended working time is desired.

1.0 INTRODUCTION

Industry by-products such as ground granulated blast furnace slag (slag) and fly ash have been used for some years in combination with ordinary Portland cement Type GP to form blended cements, Type GB. AS 3972 (1) defines Type GB cement as containing GP cement with greater than 5% slag and/or fly ash or up to 10% silica fume, although GB cements containing silica fume are not used in road stabilisation. Whilst primarily used in the manufacture of concrete, Type GB cement is also used for insitu stabilisation of road pavements. GB cements react slower than GP cement and therefore provide greater working time for road contractors.

Recent years has seen the emergence of cementitious binders which combine slag and/or fly ash with hydrated lime to offer the stabilisation industry an even greater choice. This paper will present the findings of recent research which investigated the effectiveness of various cementitious binders on marginal pavement materials. These binders included GB cement, slag/lime blends, lime/fly ash and Blue Circle Southern Cement's alkali-activated slag (commercially known as *Roadment*). The paper will also briefly summarise the development of this product and feature a review of a Transport SA road stabilisation project that utilised this new stabilisation binder, including some post-construction analysis.

Materials commonly known as 'marginal' or 'non-standard' include naturally occurring road making materials such as alluvial or colluvial sands and gravels, pyroclastic tuffs and scorias, and chemically formed gravels such as calcretes and laterites. Even though these materials can generally be used without processing, in order to compensate for unfavourable characteristics such as high plasticity, poor grading or lack of cohesion, various forms of mechanical, bituminous and cementitious stabilisation may be used. Furthermore, processed ripped or soft rocks may also be classed as marginal materials. These are normally confined to subbase construction, and include weathered granite, siltstones and sandstones (17).

2.0 DEVELOPMENT OF SLOW-SETTING BINDERS

Slag/lime and lime/fly ash blends are known as “slow-setting” binders. A combination of factors has led to the development and increased use of such binders. The primary factors are:

- the need for Australian industry to reduce waste material going to landfill and the need to find markets for these materials;
- the need for the cement industry to reduce its greenhouse gas emissions;
- the need for the relatively small Australian cement industry to become more globally competitive and reduce costs in the face of Asian imports;
- the need for greater working times in some stabilisation projects (which is available with slow-setting binders); and
- the need to reduce the extent of shrinkage cracking in stabilised pavements

Noting the above factors, the demand for slow-setting binders and the reduced road research funds from traditional sources, in 1997 Blue Circle Southern Cement (VIC) Ltd (Blue Circle) commenced research into the development of an alkali-activated slag (AAS) product specifically for use in road stabilisation. As will be demonstrated below AAS is also classified as a slow-setting binder.

2.1 Nature of slag and fly ash and how they work in the presence of cement or lime

Slag and fly ash are known as pozzolans. A pozzolan is defined as a siliceous or aluminosiliceous material that in itself possesses little or no cementitious value but which in finely divided form chemically reacts with calcium hydroxide released by the hydration of Portland cement or lime to form compounds possessing cementitious particles (2).

The combination of these pozzolans with hydrated lime are also known as supplementary cementitious materials (SCM's). Hydration reactions of SCM's are slow but continue over a long period, provided that adequate moisture is present. The rate of reaction increases with increasing temperature.

The slow-setting nature of SCM's is an advantage where extended working time is required for compaction and finishing. GP cement usually only provides 2-3 hours working time between mixing and compaction. GB cements offer 3-5 hours and SCM's offer 8-12 hours, depending on ambient conditions. Depending on location, SCM's may also offer economic benefits over cements.

The other major benefit of the use of GB cement and SCM's is the likelihood of reduced adverse effects of shrinkage cracks in bound pavements. The slower setting nature of these materials together with appropriate curing, trafficking and sealing methods tends to produce cracking patterns that are more manageable than those that are produced with the use of GP cement (2).

Slag/lime blends have been used extensively in NSW for a number of years and are now also popular in north-western Victoria. Lime/fly ash blends have been popular in South Australia and recently Transport SA has also adopted use of AAS (see Dukes Highway report, below).

2.2 Development of Alkali-Activated Slag (Blue Circle Southern Cement's, Roadment)

Blue Circle's manufacturing plant, with a capacity of 500,000 tonnes per annum, is located in south-west Victoria at Waurin Ponds, near Geelong. Given the now global nature of the cement industry and the need for Australian industry to reduce greenhouse gas emissions, Blue Circle continues to pursue efficiencies in its operations and methods to reduce natural gas consumption. Natural gas is used as a fuel to heat the kiln and produce clinker from the naturally occurring limestone located in the nearby quarry. The clinker is ground to produce cement.

One measure adopted at this plant which has led to a reduction in natural gas consumption and significant environmental benefits is the burning of alternative fuels in lieu of the natural gas. The use of slag and fly ash in lieu of Portland cement to make blended cement also contributes to a reduction in fuel consumption and conservation of raw materials.

Continuing on this theme of waste and energy reduction, Blue Circle sought a greater use for its high-alkaline clinker by-product. This by-product is unique to the manufacturing process at Waurin Ponds and is also used as a mineral filler in asphalt with some disposed to landfill.

Blue Circle's internal research sought to develop a product that utilised a combination of the alkaline by-product and slag. Similar to the function of lime in slag/lime blends, this internal research demonstrated that the alkaline by-product activated the slag to form cementitious bonds with slow strength gains.

3.0 VIC ROADS EVALUATION OF ALKALI-ACTIVATED SLAG

In March 1998, VicRoads Materials Technology Department (3) was commissioned by Blue Circle to carry out a laboratory study on stabilisation binders, including the new AAS binder under a range of conditions. The host material selected for this evaluation was a Class 3 subbase quality crushed rock which has been used by VicRoads in other laboratory assessments of stabilisation binders (4). Whilst not representative of rural marginal pavement materials, the use of this Class 3 material enabled VicRoads to compare findings across different studies. The key findings of the March 1998 research are presented below.

This testing compared the established binders, GB cement (70%/30% Portland cement/fly ash) and 85%/15% slag/lime with AAS. The aim was to compare the effects on density and unconfined compressive strength (UCS) of the crushed rock by varying factors such as binder type, binder content, delay between mixing and compaction (representing working time), curing period and curing regime. The samples were dynamically compacted by machine at 100% modified compactive effort and 100% optimum moisture content. The samples were moist cured for the required time in the laboratory at between 21-24°C. The binder content added was 3% by weight with tests also performed for 2% and 5% addition for the AAS.

3.1 The effect of delay to compaction on dry density

The laboratory program included delays to compaction of 0, 2, 4, 6, 8 and 12 hours. All tests were performed using modified compaction in accordance with AS1289.5.2.1.

The results showed that for the GP/fly ash blend, the dry density decreased with increasing delay time to compaction (see Figure 1). The rate of reduction in dry density in the case of AAS and slag/lime was not found to be significant. This confirmed that these binders are slow-setting. The GP cement/fly ash blend exhibited a significant reduction in density when compacted after 12 hours delay, which indicated the faster setting nature of this high Portland cement blend.

3.2 Analysis of UCS results

3.2.1 The effect of delay time to compaction on UCS

The UCS value was found to decrease with delay to compaction for the GP/fly ash blend (about 30% reduction after 12 hours delay), as demonstrated in Figure 2. Samples stabilised with either AAS or slag/lime showed no loss of UCS at 12 hours delay.

3.2.2 UCS gain with curing time

The UCS of samples stabilised with all three binders was found to increase with curing time (see **Table 1** and Figure 3). At 7 days, the strength gain was approximately 40%-50% that of the 90-day strength.

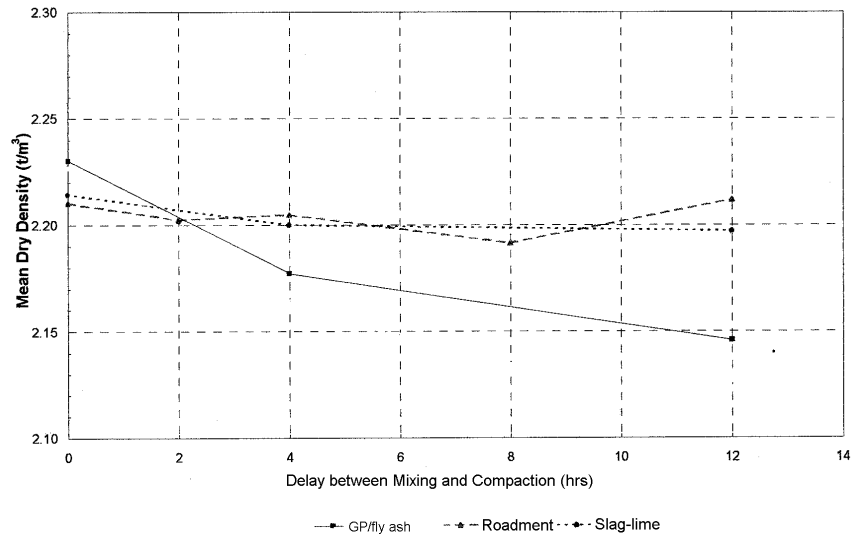


Figure 1 - Mean dry density vs delay to compaction – 3% binder

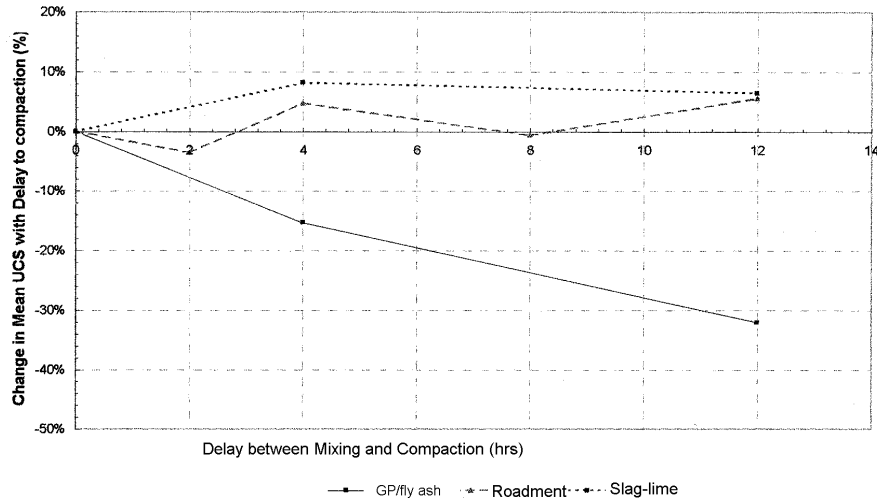


Figure 2 - Percent change in mean UCS with delay time to compaction - 3% binder

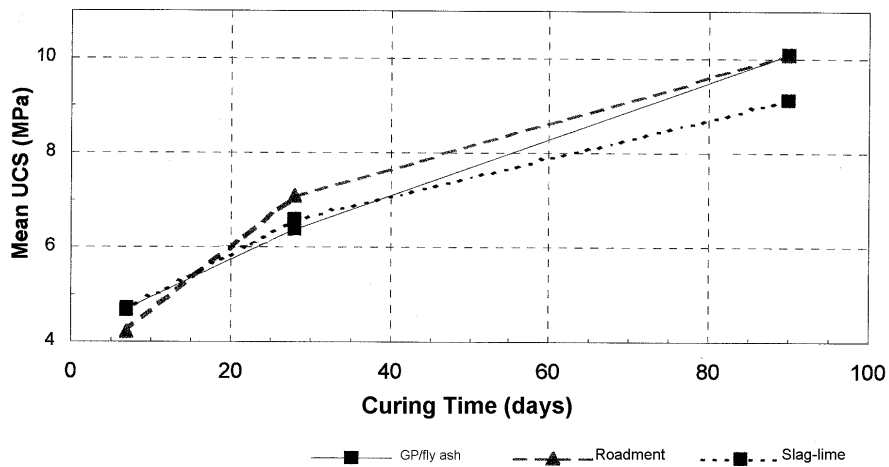


Figure 3 – Increase in UCS with curing time (zero hours delay to compaction) – 3% binder

Table 1 - The effect of curing times and delay to compaction on UCS (MPa)

Delay to compaction (hours)	Binder								
	GP/fly ash (70/30) 3%			AAS 3%			85/15 slag/lime 3%		
	Curing time (days)			Curing time (days)			Curing time (days)		
	7	28	90	7	28	90	7	28	90
0	4.7	6.4	10.1	4.2	7.1	10.1	4.7	6.6	9.1
4	3.9	6.1	7.8	4.7	7.7	9.4	4.9	7.7	9.4
12	2.8	4.7	7.0	4.7	7.5	10.0	4.9	7.1	9.8

*UCS samples compacted at 100% MOD MDD and 100% OMC as per AS1289.5.2.1.

Table 1 also shows the effect of delay time to compaction on UCS for the faster setting binder, GP/fly ash (ie the UCS decreases with increasing delays) and that the effect of delays to compaction on the slow-setting binders was not significant.

3.2.3 Effect of dry density on UCS

The study found that the dry density of samples stabilised using the GP/fly ash blend decreased with delay time. No change in dry density was observed for the two slow-setting binders, AAS and slag/lime. Due to the relatively faster rate of reaction for GP/fly ash compared to the other blends, delays in compaction would cause some cementitious bonds that may have formed during the delay period to be broken by compaction, resulting in lower UCS than those with no delay following mixing.

3.2.4 Effect of binder content on UCS

The UCS of the AAS was tested at 2%, 3% and 5%. The study showed that under the same sample preparation, curing and testing conditions, UCS increases with binder content (see **Table 2**).

Table 2 – Mean UCS values for samples with different AAS binder content (delay time 2 hours)

Curing time (days)	AAS content		
	2%	3%	5%
7	2.7	3.9	6.5
28	4.3	7.3	9.9
90	6.6	9.4	14.0

*UCS samples compacted at 100% MOD MDD and 100% OMC as per AS1289.5.2.1.

3.3 Conclusions from VicRoads report

The GP/fly ash binder had a reduction of dry density of 0.8% per hour, whilst the AAS and slag/lime did not exhibit any significant reduction in density even up to 12 hours delay between mixing and compaction.

As delays to compaction exceeded 2-4 hours, the slow-setting binders showed superior UCS relative to the faster-setting GP/fly ash blend, particularly at longer curing times.

With regard to working time the study concluded the new product, AAS was similar in performance to 85/15 slag/lime. It also recommended that for these binders at temperatures between 20°C and 25°C VicRoads then 3-hour limit for completion of compaction could be extended to 8 hours. This recommendation has since been adopted in VicRoads Standard Specification Section 307 'Insitu stabilisation of pavements with cementitious binders', with the maximum allowable working time increased to 8-12 hours (5). The study also provided valuable information towards the re-writing of Section 307 (5), which now allows for a greater range of binders.

4.0 ANALYSIS OF VARIOUS RESEARCH AND TESTING PROGRAMS

4.1 Woollen rises - sandstone gravel (Parilla sand formation)

The Woollen Rises Sandstone gravel is a marginal pavement material used in road construction in north-western Victoria. It consists of a fine to medium grained, quartzose, well sorted, slightly micaceous sand. It is derived from the Woollen Rises quarry at Charlton, Victoria.

A research and development project was undertaken by VicRoads in 1998 (6) to investigate the various mechanical and chemical stabilisation treatments, in terms of their effectiveness when used in conjunction with a number of marginal materials used throughout south-western and western Victoria. The Woollen Rises Sandstone was one of the marginal materials used in this study. The test results obtained are shown in Table 3.

Table 3 – VicRoads (1998) results for Woollen Rises sandstone

Blend	Mean UCS* (MPa) 7 day cured	Lab Soaked CBR (%)	PL (%)	LL (%)	PI
None	0.5	90	18	26	8
1% hydrated lime	1.1	160	-	-	-
2% GP Cement	1.9	210	-	-	-
2% GB Cement	1.6	180	-	-	-
2% 85/15 s/l	1.0	140	-	-	-

*UCS samples compacted using vibratory methods in 3 layers at 98% MOD MDD and 90% OMC.

In 1999, Chadwick Geotechnical Testing Pty Ltd (7) was commissioned by Blue Circle to undertake a research study to determine the effect of the addition of slow-setting binders on the plasticity index (PI), 7-day and 28-day UCS. The binders used were, 3% AAS and 3% slag/lime in the ratios 85/15, 70/30 and 60/40. These results have been summarised in the Table 4.

Table 4 - Chadwick (1999) results for Woollen Rises sandstone

Blend	Mean UCS** (MPa) 7 day cured	Mean UCS** (MPa) 28 day cured	PL (%)	LL (%)	LS (%)	PI
Raw	0.2	N/A	20	25	2.4	5
3% 85/15 s/l	1.4	1.5	28	31	1.2	3
3% 70/30 s/l	2.5	2.5	30	33	0.8	3
3% 60/40 s/l	2.4	2.5	32	32	0.0	0
3% AAS*	1.4	1.4	33	36	0.8	3

*Commercially known as *Roadment*

**UCS samples compacted using dynamic methods in 3 layers at 98% MOD MDD and 100% OMC.

One problem, which affects stabilised pavements, is reflective cracking. Reflective cracking may be the result of a variety of failure mechanisms yet to be fully understood. However, it is believed that shrinkage cracking may contribute to the formation of reflective cracks.

It is difficult to predict the amount of shrinkage cracking that may take place following stabilisation of a road pavement. Factors affecting the appearance of such cracks include the initial moisture content, ambient temperature, differential and rapid moisture changes (drying), swelling potential of the pavement material (PI, linear shrinkage, swell) and the type and quantity of binder used.

Low plasticity materials (PI < 10) are preferred in the construction of road pavements. This is mainly due to their workability and moderate susceptibility to moisture changes. However, most marginal materials fail to conform to construction standards regarding plasticity and particle size distribution. Hence the importance in achieving a reduction in PI and linear shrinkage during stabilisation.

The research (7) showed that 3% 60/40 slag/lime achieved a 100% reduction in PI and linear shrinkage. Although the reduction in linear shrinkage may be interpreted as beneficial, the low PI may result in lack of cohesion and poor workability. Of the other blends, all achieved a 40% reduction in PI irrespective of the binder type. However, mixes using 3% AAS and 3% 70/30 slag/lime achieved a 65% reduction in linear shrinkage compared to 50% reduction using 3% 85/15 slag/lime. Even though other factors must also be considered, a significant reduction in linear shrinkage would indicate a lower risk of the formation of shrinkage cracks.

The research study revealed that at least 90% of the strength gain achieved at 28 days occurred during the first 7 days.

It should be noted that in Victoria, VicRoads (5) requires slow-setting binders to achieve an UCS of 1.0 MPa at 7 days, whereas a fully bound pavement applicable for deep-lift stabilisation should achieve an UCS of 2.5 MPa.

The UCS results indicated that modification of the material to form a lightly bound layer can be achieved by using either 3% 85/15 slag/lime or 3% AAS. A fully bound layer could be achieved by using 3% 70/30 or 3% 60/40 slag/lime.

4.2 Wimmera Highway, Rupanyup and Sunraysia Highway, Cope Cope (VIC)

In mid 1999, the north-western region of VicRoads planned to rehabilitate the Wimmera and Sunraysia Highways at the above locations using 75/25 slag/lime. In an effort to continue its research on slow-setting binders with different marginal materials, Blue Circle commissioned testing (8) as summarised in **Tables 5 and 6**. In both cases the material at these locations was classified as Clayey Sandy Gravel.

The UCS testing included 1-day and 7-day testing. Tests performed at 1-day included rapid curing of samples at 45°C and 90% relative humidity for two hours prior to testing. This was done in order to determine the short-term strength gain of the different blends. All 7-day samples were cured at 23°C and 90% relative humidity for the entire curing period.

Table 5 – UCS results for Wimmera Highway, Rupanyup

Blend	Mean UCS*	Mean UCS*	PL (%)	LL (%)	LS (%)	PI
	(MPa) 1 day rapid cured	(MPa) 7 day cured				
Raw	0.3	-	15	24	3.0	9
2% 75/25 s/l	0.8	1.4	19	24	2.0	5
2% AAS	0.9	1.2	19	23	1.0	4
3% AAS	1.0	1.8	20	22	0.5	2

*UCS samples compacted using dynamic methods in 3 layers at 98% MOD MDD and 100% OMC.

As shown in the above Table 5 all blends achieved over 1.0 MPa as required by VicRoads (5) and a significant reduction in PI.

The research showed that 2% 75/25 slag/lime achieved a 45% reduction in PI and a 30% reduction in linear shrinkage. However, mixes using 2% and 3% AAS achieved a 55% and 80% reduction in PI and 65% and 85% reduction in linear shrinkage respectively.

Table 6 – UCS results for Sunraysia Highway, Cope Cope

Blend	Mean UCS*	Mean UCS*	PL (%)	LL (%)	LS (%)	PI
	(MPa) 1 day rapid cured	(MPa) 7 day cured				
Raw	0.3	-	18	24	3.5	6
2% 75/25 s/l	0.6	0.6	23	27	1.5	4
2% AAS	0.7	1.1	20	25	1.0	5
3% AAS	0.9	1.3	22	25	1.0	3

*UCS samples compacted using dynamic methods in 3 layers at 98% MOD MDD and 100% OMC.

The 75/25 slag/lime blend as shown in Table 6 did not achieve the 1.0 MPa, as required by VicRoads (5).

These results showed that mixes using 2% and 3% AAS achieved comparable reduction in PI to that of 2% 75/25 slag/lime, but a 15% greater reduction in linear shrinkage.

4.3 West Wimmera Shire

In January 2000, testing was carried out in order to determine the strength gain of a sandy gravel pavement material when stabilised with 3% AAS (9). This material is common within the West Wimmera Shire, which borders South Australia in western Victoria. The Shire required a slow-setting binder to insitu stabilise two local roads used by harvest transport vehicles.

At 7 days curing, the UCS increased from 0.4 MPa to 1.0 MPa for the South Service Road and from 0.7 MPa to 1.5 MPa for the Lillimur Extension Road. On the basis of these results the Shire proceeded with the stabilisation in February 2000.

Table 7 – UCS results for Wimmera Highway, Rupanyup

Blend Location	Mean UCS* (MPa)	Mean UCS* (MPa)
	7 day cured South Service Rd	7 day cured Lillimur Extension Rd
Raw	0.4	0.7
3% AAS	1.0	1.5

*UCS samples compacted using dynamic methods in 3 layers at 98% MOD MDD and 100% OMC.

4.4 Urana Shire

Urana Shire Council in southern NSW commissioned laboratory testing (12) on some locally available materials to determine the increase in CBR by the addition of various cementitious binders. The results are presented in Tables 8, 9 and 10 below.

Table 8 – Urana Shire CBR testing with Screen Pit material and various binders

Source of sample Binder type and content	Screen Pit			
	Nil	3% 85/15 slag/lime	3% GP cement	3% AAS (Roadment)
Swell (%)	0.0	0.0	0.0	0.0
CBR (%)*	16.0	50.0	120.0	70.0

* Standard compaction used.

Table 9 – Urana Shire CBR testing with Shoulder Gravel material and various binders

Source of sample	Shoulder Gravel			
Binder type and content	Nil	3% 85/15 slag/lime	3% GP cement	3% AAS (Roadment)
Swell (%)	0.1	0.0	0.0	0.0
CBR (%)*	45.0	90.0	130.0	60.0

* Standard compaction used.

This testing was performed to determine the most appropriate treatment for stabilisation of Jerilderie Road, Urana. Following subgrade stabilisation using 3% GP Cement, the existing shoulders were stabilised using 3% 85/15 slag/lime, as this yielded the highest CBR. 3% AAS was adopted for stabilisation of the gravel base Screen Pit material.

Following the success of AAS on the Jerilderie Road project, Council selected AAS to stabilise Milthorpe Street in the township of Urana based on the CBR results below (13).

Table 10 – Urana Shire CBR testing with Gierschs Pit material and various binders

Source of sample	Gierschs Pit	
Binder type and content	Nil	3% AAS (Roadment)
Swell (%)	-	-
CBR (%)*	90.0	160.0

* Standard compaction used.

5.0 TRANSPORT SA PROJECT: DUKES HIGHWAY OVERTAKING LANES, KEITH SA

5.1 Design methodology and laboratory testing

As part of the traffic safety enhancements for the Dukes Highway, a number of overtaking lanes and an additional third lane have been constructed by Transport SA between Keith and the Victorian Border. Previous overtaking lanes constructed between Tailem Bend and Keith have all been granular configurations with standard crushed rock being transported up to 100 km. These lanes have performed poorly under heavy traffic loading (1.3×10^7 ESA) through rutting at the joint, some outer wheel path shear failures and slick spray seals from aggregate penetration into the 20mm base course.

In an effort to improve performance of the passing lanes at Keith, Transport SA proposed to stabilise the calcrete limestone pavement material. However, previous experience with 4% cement in a deep lift insitu process with limestone had not performed **Figure 4** and therefore a modified rather than a fully bound pavement was favoured, together with the adoption of a slow-setting binder and two-layer construction.



Figure 4 – Failed cement stabilised pavement (4% Cement), SA

Laboratory resilient modulus testing (10) suggested that 2% lime/fly ash (1:1), 2% “Stabilig 2LC” or 2% Blue Circle’s product AAS shown as “Roadment” in **Figure 5** would provide a stiffness of around 2000 MPa, as required by Transport SA . Subsequent CIRCLY analysis provided a design depth of 420mm (rutting and fatigue considerations) and 450mm was adopted.

To ensure that adequate compaction was achieved through the full depth of the pavement, a two-layer construction process was recommended (**see Figure 6**).

AAS was selected by the contractor as the preferred alternative on the basis of performance, ease of application and economics. The advantage of 2% AAS was the fact that it is supplied as a blended product and could be spread in one application compared to 2% lime/fly ash (1:1), which required the lime and the fly ash to be spread in two separate applications. This was a more cumbersome, time consuming and expensive method of construction compared to the pre-blended AAS.

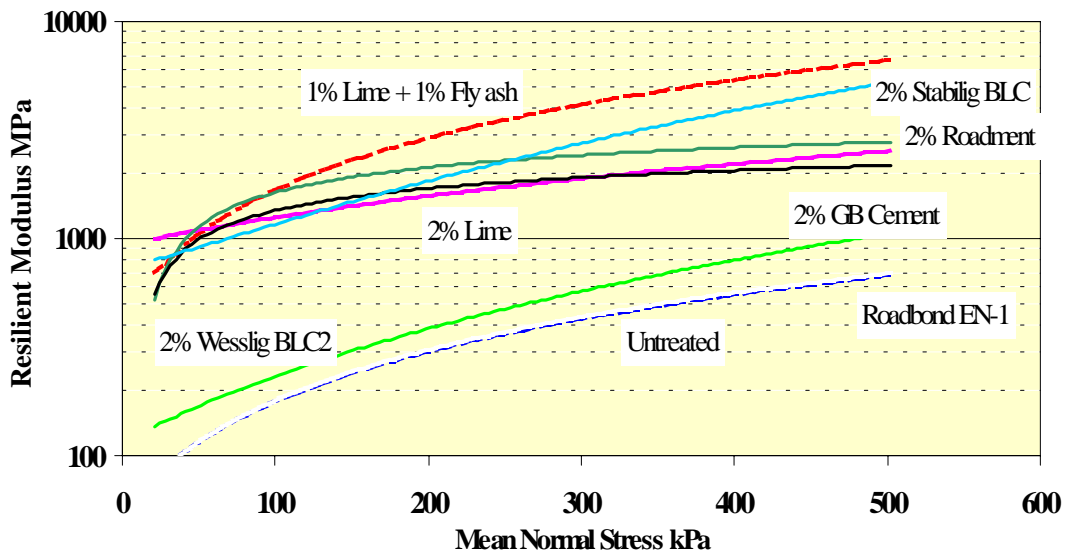


Figure 5 – Laboratory resilient modulus testing with various binders for Dukes Highway overtaking lanes, Keith, SA

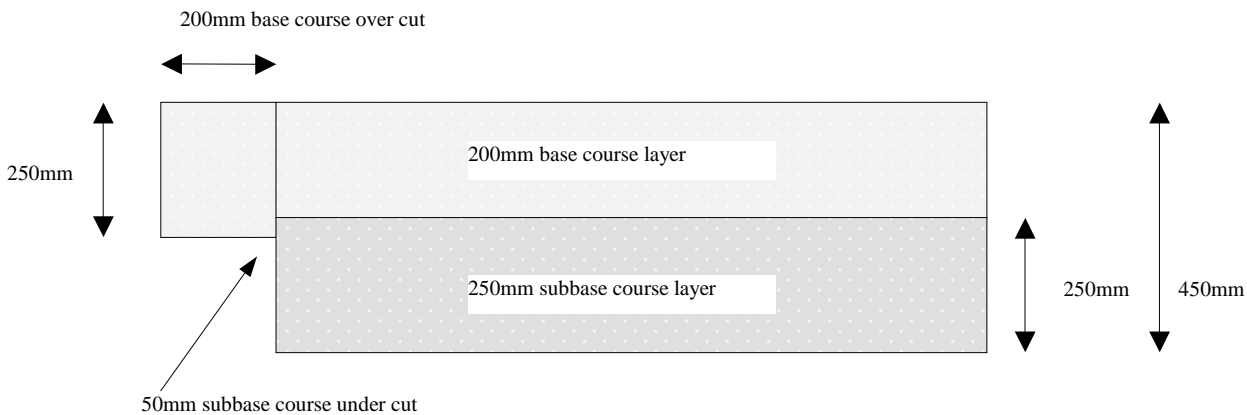


Figure 6 – Construction Detail (Dukes Highway, South Australia).

5.2 Preliminary evaluation of constructed pavements

The overtaking lanes were constructed in April-June 2000. Falling weight deflectometer (FWD) back analyses and coring (to determine insitu UCS's) of the completed pavement was undertaken to evaluate the as-constructed pavement (11). This evaluation would also provide information that would allow a more confident design approach of future overtaking lanes, including a refinement of the design thickness and/or binder proportions.

The intent of the design philosophy discussed above was to build a modified pavement with a stiffness below 2000 MPa to avoid the shrinkage and subsequent fatigue failures observed with the cement bound stabilised pavement east of Bordertown. The design depth was such that it met both subgrade rutting and fatigue criteria (in the event of it being bound).

The UCS determined from cores taken from the pavement in July 2000 indicated that, in fact, a bound pavement had been constructed, due to the AAS binder producing higher strengths than expected. These UCS results varied between 2.7 MPa and 6.4 MPa (pavement age approximately 6 weeks to 3 months). The FWD back analyses (undertaken about 21 days age) also support a bound pavement. UCS's on field-prepared specimens produced a 28-day strength of 1.7 MPa and 56-day strength of 2.3 MPa. Whilst this was a good result in itself, the field cores displayed much higher UCS results, leading to the bound pavement conclusion.

5.3 Future overtaking lanes at Dukes Highway, Keith

In July 2000, Transport SA advised the authors that, given the above results, the next set of overtaking lanes at the Dukes Highway would be designed on the basis of a fully bound pavement. AAS binder will be increased from 2% to 5%. The 5% binder content is expected to reduce erosion and resist fatigue failure.

6.0 COSTS OF STABILISED PAVEMENTS

A study by Moffat, et al (14) (also reported as APRG Technical Note 9) (15), conducted Accelerated Loading Facility (ALF) trials of unbound and stabilised pavements. This research concluded that the relative cost of constructing the stabilised pavements was 2 to 3 times the cost of constructing the unbound marginal pavement (Woollen Rises sandstone). The performance, however of the stabilised pavements, in terms of deformation under repeated heavy loading (equivalent to a 16 tonne axle load), was 6 to 10 times superior to that of the unbound pavement.

7.0 CONCLUSIONS

The various research projects and subsequent case studies discussed in this paper have indicated that the use of slow-setting binders, can be very effective in enhancing the engineering properties of marginal pavement materials, especially when used for the insitu stabilisation of road pavements.

One of the advantages of slow-setting binders over more traditional stabilisation binders such as GP Cement is greater working time. As shown by the research data and acknowledge by VicRoads (5), materials stabilised with slow-setting binders have shown less susceptibility to losses in strength from delays in compaction after mixing (research testing showed that GB Cement experience significant reductions in strength with increased delay in compaction after mixing).

It should be noted that following the laboratory study of AAS (3), VicRoads has included AAS in its Standard Specification, Section 307 (5). AustStab (Australian Stabilisation Industry Association) has also included AAS in the binder definitions of its model specification for local government road stabilisation (16).

Also, it was confirmed by the testing carried out by Chadwick Geotechnical (7) on Woollen Rises Sandstone, that slow-setting binders were effective in reducing PI and linear shrinkage. The increase in strength, observed by UCS testing, indicated that most binders successfully complied with VicRoads (5) (7-day UCS of at least 1.0MPa). However, the newly developed AAS was found to achieve greater reductions in PI and linear shrinkage, as well as higher UCS than 85/15 slag/lime.

At least one case study indicated that in eastern South Australia (Dukes Highway, Keith), AAS may be more cost effective than the traditional treatment using lime/fly ash, and less prone to fatigue failure than GP Cement.

It must be noted that the research highlighted some of the limitations in the use of slow-setting binders. These could be of concern if the pavement is subjected to early heavy trafficking, particularly during cold weather. Due to their slow-setting nature, the rate of strength gain is normally much slower than that of GP or GB cements, therefore, the short-term strength should be considered carefully during design, as this may be low for at least the first 7 days.

The research showed that slow-setting binders, particularly newly developed blends, such as AAS, can be used successfully to enhanced the engineering properties of marginal materials. However, it must be noted that the degree of effectiveness of any stabilisation treatment appeared to be material dependent. The engineering properties and mineralogy of the raw pavement material have a significant effect on the magnitude of strength gain and percentage of binder required. Therefore, laboratory testing should be carried out to determine the optimum stabilisation treatment.

8.0 REFERENCES

1. AS 3972 – 1997 (1997) *Portland and blended cements*, Standards Association of Australia, 1997.
2. *Guide to Stabilisation in Roadworks* (1998) AUSTROADS, Sydney, NSW.
3. Yeo, REY, Gazzard, G, Choummanivong, L (1998), Evaluation of New Products for use in Road Stabilisation, Confidential Contract Report for Blue Circle Southern Cement Ltd, VicRoads Materials Technology Department, Burwood East, Vic.
4. GEOPAVE Technical Note 15 (2000), *Stabilisation – cementitious Blends Incorporating GGBFS*, GEOPAVE, Burwood East, Vic.
5. VicRoads Standard Specifications, Section 307 (1999), *Insitu Stabilisation of Pavements with cementitious Binders*, VicRoads, Kew, Vic.
6. VicRoads Research and Development Project, Final Report, Project No 695, Report No TR 110 (1998), *Stabilisation of Marginal Materials*, VicRoads Materials Technology Department, Burwood East, Vic.
7. Woollen Rises Laboratory Study, GEN0155-1 (2000), Confidential Contract Report for Blue Circle Southern Cement Ltd, Chadwick Geotechnical Testing Pty Ltd, Narre Warren, Vic.
8. Wimmera Highway, Rupanyup and Sunraysia Highway, Cope Cope Laboratory Study, GEN0103-1 (1999), Confidential Contract Report for Blue Circle Southern Cement Ltd, Chadwick Geotechnical Testing Pty Ltd, Narre Warren, Vic.
9. West Wimmera Laboratory Testing, GEN0205-1 (2000), Confidential Contract Report for Blue Circle Southern Cement Ltd, Chadwick Geotechnical Testing Pty Ltd, Narre Warren, Vic.
10. Pavement Design Report, RN 7800 Dukes Highway, Report No RN7800-RCA, (1999), Internal Report, Transport SA Materials Technology Section, Walkley Heights, SA.
11. Correspondence between Bob Andrews, Transport SA and Maurice Serruto, Blue Circle Southern Cement regarding Dukes Highway Evaluation (2000).
12. Shoulder Widening MR59 Laboratory Testing, Aitken Rowe Testing Laboratories Pty Ltd, Wagga Wagga NSW for Urana Shire Council, NSW.
13. Quality Control Testing Aitken Rowe Testing Laboratories Pty Ltd, Wagga Wagga NSW for Urana Shire Council, NSW.
14. Moffat MA, Sharp KG, Vertessy NJ, Johnson-Clarke JR, Vuong BT and Yeo REY (1998), *The Performance of Insitu Stabilised Marginal Sandstone Pavements*, APRG Report No 22 and ARRB TR Research Report No 322.
15. APRG Technical Note 9 (1999), *Insitu Stabilisation of Marginal Pavement Material*.

16. Model Specification for Insitu Stabilisation of Local Government Roads using cementitious Binders including Lime (2000), Australian Stabilisation Industry Association (AustStab), Sydney, NSW.
17. VicRoads Technical Bulletin 39 (1998), *Guide to General Requirements for Unbound Pavement Materials*, VicRoads Materials Technology Department, Burwood East, Vic.

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10.0 AUTHOR BIOGRAPHIES

Maurice Serruto

Maurice Serruto is Pavement Engineer for Blue Circle Southern Cement (Vic) Ltd and has held that position since its creation in October 1998. His role with Blue Circle is primarily in the area of road stabilisation and includes the provision of technical advice to specifiers and contractors in this industry. Maurice works closely with local government and state road authorities in Victoria, South Australia and NSW, facilitating research and laboratory testing programs to further knowledge of the behaviour of various materials stabilised with cementitious binders. Maurice is Blue Circle's representative on the Australian Stabilisation Industry Association's committee.

Prior to Blue Circle Southern Cement, Maurice was employed for two years as Divisional Engineer with the Cement and Concrete Association of Australia (C&CAA) with responsibilities in the area road stabilisation and major concrete roads and streets. In this role, Maurice was C&CAA's representative at the Australian Pavement Reference Group and the Australian Pavement Design Guide Reference Group.

Maurice was also employed for eight years with Hume City Council in a variety of design and construction engineering roles. His experience prior to Hume involved two years with soils/structural engineering consultants and one year with VicRoads.

Maurice obtained his Bachelor of Engineering degree from the University of Melbourne in 1985 and also holds a Post-Graduate Diploma in Municipal Engineering and Management from Victoria University of Technology. Maurice is currently studying towards a Graduate Certificate in Corporate Management at Deakin University.

Lucas Pardo

Lucas Pardo obtained his Bachelor of Engineering degree in Civil Engineering from Victoria University of Technology, and he is currently completing a Masters of Engineering degree in Pavement Technology.

He has worked at the Materials Technology Department laboratories and Special Research Section at VicRoads (now GeoPave). Some of the projects he has been involved are: monitoring of pavement performance on rural highways in expansive clay areas; design and installation of moisture barriers for pavements and durability of structural concrete.

He joined the Chadwick Group in 1997, and he is currently the manager of Chadwick Geotechnical Testing Pty Ltd. In that role, he has been involved in the investigation and design of over 300 road pavements (from local light traffic roads to major roads and highways). He has coordinated extensive research in the areas of pavement performance; monitoring of subgrade soils; insitu stabilisation of existing pavements; road rehabilitation and reconstruction. He has written and presented many technical papers in Australia and overseas.