Detailed Investigation of the Performance of GB Cements in Pavement Stabilisation Works

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Introduction

Although Stabilisation plays an important part in the construction and maintenance of road and other pavements in Australia, and although GB Cements are the most widely used binder additives, there is still a lack of knowledge and understanding of the properties of GB Cements in their use in stabilisation.

There has been much anecdotal information from past experience using GB (General Purpose Blended) Cements. There have also been a number of research activities involving GB Cements as a part of wider investigations of stabilisation binders. One problem with some of this previous research is that its scope has been so broad that it has not been able to properly identify the characteristics of the performance of GB Cements in their use in the pavement stabilisation sphere.

With this in mind, Stabilised Pavements of Australia Pty. Limited set up a detailed research testing programme in co-ordination with Brisbane City Council. This testing programme was specifically designed to be both detailed and focused in an effort to obtain clear and definitive information on the performance of GB Cements in pavement stabilisation work.

Aim

The aim of this project was to supplement the information already gained by the “GIRD Project” carried out in South Australia in 1995. The GIRD Project had a very broad scope and had limited results for specific areas. The limitations of the quantity, consistency and specific nature of the results from this previous project made it difficult to glean definite conclusions from the information obtained. Hence, the research in this current project was to follow on from GIRD but to be focused solely on materials from Brisbane City Council and was intended to provide more specific information and understanding on different GB Cement Blends and their working reaction with the road materials most commonly found in Council’s region.

These more specific research results, allied with the complimentary information from the GIRD project and other historical information, would contribute to the further development in the understanding of how and when GB Cements perform in stabilisation work, their practicality of use and their environmental benefits.

This refinement in our understanding of the different GB Cements would in turn assist in

- more efficient and appropriate cementitious binder selection in terms of cost, practicality and environmental benefits
- improvement in the uses and effects of stabilisation in pavement construction and rehabilitation
- maximising the benefits of cementitious stabilisation by assisting in the formulation of best field operation practices.

Procedure Overview

Three (3) of the most common pavement materials to be encountered in Council's rehabilitation operations were tested with four (4) different GB Cement blends available in Brisbane and commonly found in the eastern States of Australia, as listed below.

Nominated Pavement Materials
- Mt. Coot-tha Type 2.1 Fine Crushed Rock
- Pine Mountain Crusher Run Gravel
- Decomposed Granite

Nominated GB Cement Blends
- 70/30 Cement/Fly Ash
- 70/30 Cement/Slag
- 75/25 Cement/Fly Ash
- 40/60 Cement/Slag

See Table 1 for the typical properties of the three nominated pavement materials from Brisbane City Council.

Table 1 Typical properties of the three pavement materials from Brisbane City Council.

Property		Mt. Coot-tha Type 2.1 Fine Crushed Rock	Pine Mountain Crusher Run	Decomposed Granite Gravel
	53.00 mm	100	100	100
	37.50 mm	91	100	100
	26.50 mm	-	-	-
	19.00 mm	67	99	99
Gradings:	13.20 mm	-	-	-
% Passing	9.50 mm	52	88	64
Sieve Size	6.70 mm	-	-	-
	4.75 mm	41	62	42
	2.36 mm	28	36	30
	1.10 mm	-	-	-
	0.600 mm	-	-	-
	0.425 mm	10	11	15
	0.300 mm	-	-	-
	0.150 mm	-	-	-
	0.075 mm	5	5	7
Liquid Limit [%]	18	24	31	
Plastic Limit [%]	17	19	21	
Plasticity Index P.I. [%]	1	5	10	
Note: The "typical" properties are result of averaging many results				

The testing regime consisted of testing all three materials with 4% by weight of each of the four GB Cement Blends for:

i] **Strength**
Unconfined Compressive Strength [U.C.S.] using the standard moisture curing procedure for different curing periods
- 7 day U.C.S. testing
- 28 day U.C.S. testing

ii] **Flexural and Stiffness Properties**
- 7 day Resilient Modulus
- 28 day Resilient Modulus
- 90 day Resilient Modulus

iii] **Shrinkage**
- using standard shrinkage testing at 7 and 20 days

iv] **Workability**
- initial and final set times

Background

General Purpose Portland Cement [GP] and General Purpose Blended Cements [GB] are defined and specified by the Australian Standard AS3972. "Clause 4.3 Blended Cement. A hydraulic cement containing Portland cement and a quantity greater than 5% of fly ash or granulated iron blast-furnace slag or both."

Apart from the minimum restriction of 5% and the fact that the Fly Ash and/or blast-furnace slag need to comply with their own relevant standards for Fly Ash and slag, the Cement Standard for Blended Cement is basically a performance based specification. That is, the quantity of Fly Ash or slag or both, to be used in a blended cement, is dependent on setting times and minimum 7 and 28 day strength requirements as detailed in the standard.

Table 2 illustrates a typical chemical analysis of Portland Cement, Ground Granulated Blast Furnace Slag and Fly Ash. From these figures it can be seen that slag [GGBFS] has a chemical composition much more like that of cement than Fly Ash. Hence, although both slag and Fly Ash are used successfully in blended cements throughout the World, as a rule a set quantity of slag in a blended cement will result in a slightly higher strength being developed by that cement than for a blended cement with an equal quantity of Fly Ash. This is verified in the extracts from Road Rehabilitation by Recycling [Properties of Australian Soils Stabilised with Cementitious Binders], "The GIRD Project" report.

The basic cement hydration reaction is:

Cement + water > calcium silicate hydrates + calcium aluminate hydrates
[pozzollanic reactions]

Fly Ash is low in calcium and so requires $Ca[OH]_2$ from the cement to complete the pozzolanic reaction. GGBFS has its own calcium supply, but requires activation by the formation of $Ca[OH]_2$ in the cement to commence the pozzolanic reaction.

Table 2 Typical chemical characteristics of cement, fly ash and ground granulated blast furnace slag [GGBFS].

Chemical	Percentage Composition		
	Portland Cement	**GGBFS**	**Fly Ash**
CaO	64.0	41.0	4.4
SiO_2	22.0	32.6	55.0
$A1_2O_3$	4.5	12.8	25.0
Fe_2O_3	3.5	1.3	9.0
MgO	1.4	7.2	1.5
Na_2O, K_2O	0.7	2.6	1.8
SO_3	2.4	0.03	0.4

Strength Test Results

Table 3 summarises the Unconfined Compressive Strength test results at 7 and 28 days respectively for mixes of each of the four nominated Blended Cements at 4% by weight with each three nominated pavement materials.

The results exhibited good consistency both in their relationship with each other and the general trends that they are seen to follow. They are also consistent with other previous research work, which although similar in some respects, has not been so specific as this work with Brisbane City Council's material.

Some of the trends that can be clearly seen from these results are:

- all of the four GB Cements gave higher strength results when mixed with the Mt. Coot-tha materials and consistently lower results for the Decomposed Granite, while the Pine Mountain material strengths were in between these upper and lower results.

- equivalent quantities of slag in the different blends tend to be slightly more efficient in developing strength than Fly Ash. The 70/30 cement/slag blend consistently developed higher strengths than the 70/30 and 75/25 cement/Fly Ash blends.
- the higher slag content blend, the 40/60 cement/slag blend, developed strength generally equal to or slightly higher than the 70/30 and 75/25 cement/Fly Ash blends.
- although the 70/30 cement/slag blend consistently produced higher strengths than the other three blends, the other three blends produced consistently similar strengths with the 40/60 cement/slag blend generally giving results slightly greater than the other two cement/Fly Ash blends.
- all of the blends gave strengths with all of the pavement materials consistently in the envelope that would be expected with 4% cement by weight.

Table 3 Unconfined Compressive Strength with 4% GB cement by weight.

Binder Type		
	Ave. 7 day UCS (MPa)	**Ave. 28 day UCS (MPa)**
	Mt. Coot-tha Type 2.1 FCR	
70/30 Cement/Fly Ash	2.2	4.5
70/30 Cement/Slag	4.3	8.4
75/25 Cement/Fly Ash	2.5	4.9
40/60 Cement Slag	4.3	8.3
.	**Pine Mountain Crusher Run Gravel**	
70/30 Cement Fly Ash	3.0	3.5
70/30 Cement/Slag	2.5	5.3
75/25 Cement/Fly Ash	2.1	2.8
40/60 Cement/Slag	3.0	3.9
	Decomposed Granite	
70/30 Cement/Fly Ash	2.1	2.3
70/30 Cement/Slag	3.0	4.8
75/25 Cement/Fly Ash	2.6	3.2
40/60 Cement/Slag	1.9	4.6

Flexural and Stiffness Properties [Resilient Modulus Results]

Similar to the Unconfined Compressive Strength test results, the resilient modulus results exhibited good consistency both in their relationship with each other and the general trends that they seem to follow.

Table 4 summarises the resilient modulus results obtained for 8, 28 and 91days respectively for mixes of 4% by weight of each of the four nominated Blended Cements with each of the three nominated pavement materials.

Some of the trends that can be clearly seen from these results are:

- with each of the cement blends with all the different pavement materials there is an increase in the resilient modulus with increasing age. However with the Mt. Coot-tha material there was a slight decrease from 28 days to 91 days for some unknown reason.
- similar to the U.C.S. testing, all of the GB Cements gave higher resilient moduli results at both 8, 28 and 91 days with the Mt. Coot-tha material and consistently lower results for the Decomposed Granite, while the Pine Mountain material moduli results were in between these upper and lower results.
- although the 70/30 cement/slag blend tended to give higher resilient moduli results with all pavement materials at 8 days, 28 days and at 91 days, all of the results for each of the blended cements gave consistently similar high resilient moduli figures for each of the three different pavement materials with increased age.
- in general slag seems slightly more efficient that Fly Ash as a component in GB Cements in developing Resilient Moduli.

Table 4 MATTA resilient modulus results with 4% GB cement by weight at various test ages.

Binder Type	Resilient Modulus [MPa]		
	8 Days	**28 Days**	**91 Days**
	Mt. Coot-tha Type 2.1 FCR		
70/30 Cement/Fly Ash	15,800	33,800	22,600
70/30 Cement/Slag	39,300	37,200	32,600
75/25 Cement/Fly Ash	16,900	34,400	24,800
40/60 Cement/Slag	18,700	42,100	45,800
	Pine Mountain Crusher Run Gravel		
70/30 Cement/Fly Ash	12,900	24,000	28,200
70/30 Cement/Slag	17,300	19,400	25,000
75/25 Cement/Fly Ash	13,400	23,800	22,000
40/60 Cement/Slag	10,300	21,000	26,700
	Decomposed Granite		
70/30 Cement Fly Ash	7,060	13,300	19,000
70/30 Cement/Slag	11,700	15,900	20,000
75/25 Cement/Fly Ash	11,400	14,200	25,500
40/60 Cement/Slag	10,300	12,500	24,200

Shrinkage

There have been extensive field observations made throughout Australia with regard to shrinkage in cementitious stabilisation over a number of decades. From these field observations a number of best practice field procedures have been developed to limit subsequent cracking of cementitious stabilised pavements. These include the use of efficient mixing machines; controlling the moisture content so it is ideally 1% to 2% below the optimum compaction [to keep the water/cement to a minimum]; early trafficking which helps to dissipate any cracking and controlling the drying process by the use of adequate curing operations.

Despite the plethora of field observations of drying shrinkage, there has been very little laboratory testing involving shrinkage for cementitious stabilisation.

In July 1999, a joint University of South Australia and Transport South Australia project released some information supplementary to the main GIRD testing regime, which referred to some shrinkage testing. This shrinkage testing was performed on three local South Australian gravels.

Some of the interesting findings, which came from this work and other limited work, were:

- The quantity of linear shrinkage is predominantly dependent on the pavement material and specifically the quantity and nature of any plastic fines.
- The addition of cement and cement blends reduces shrinkage marginally and this reduction in shrinkage increases with increasing binder percentage.
- The amount of shrinkage measured in the laboratory for reasonably good gravels is higher than may have been expected, with and without cementitious additives.

Through the extensive history of cement stabilisation of pavement materials in Brisbane City Council, a number of different cementitious binders have been used. These included initially GP Cement, followed by 75/25 Cement/Fly Ash, 40/60 Cement/Slag and 70/30 Cement/Fly Ash. With the use of similar machinery and stabilisation techniques, similar pavement material and curing procedures, there has been no observed variation in the shrinkage behaviour of these stabilised pavements in the field using different blended cement binders. This lack of differentiation in the shrinkage performance, as observed in the field, of the common cement blends used in cement stabilisation, is supported by other observations throughout the rest of Queensland and other areas of Australia.

In this current testing regime the three nominated pavement materials were mixed with 4% by weight of 70/30 cement/Fly Ash and 40/60 cement/slag blends of GB Cement. These six mixes were then tested for shrinkage using the Queensland Department of Main Roads Test Method No. 0128-1988. Measurements were made at 7 days and the standard 20 days.

See Table 5 for the results of this linear shrinkage testing which displayed the following characteristics:

- Both the 7 day and the 20 day shrinkage test results display good consistency both in their relationship with each other and the general trends displayed by the previous work in South Australia
- \- The nature of the stabilised gravel [i.e. the amount of plastic fines present] is the most significant factor in the degree of linear shrinkage and the addition of a cementitious binder actually reduces shrinkage
- Although the materials with the slower setting binders generally displayed slightly less shrinkage, to support the fact that there is no discernible difference in the shrinkage performance of these two GB Cements in the field, the laboratory shrinkage tests results for the 70/30 Cement Fly Ash and the 40/60 Cement/Slag are very similar for each pavement material at both 7 days and 20 days.

Table 5 Linear shrinkage test results 7 and 20-day shrinkage measurements in microstrains.

Binder Type	Mt. Coot-tha Type 2.1	Decomposed Granite	Pine Mountain Gravel
	20 day shrinkage measurements in microstrains		
70/30 Cement/Fly Ash	190	600	1280
40/60 Cement/Slag	260	480	1110
.	**20 day shrinkage measurements in microstrains**		
70/30 Cement/Fly Ash	440	1010	2010
40/60 Cement/Slag	480	860	1760

Workability

Each of the four blended cements had their initial and final set times measured using a cement/sand/water mix and the cement industry standard test procedure AS2350. **See Table 6** for the results.

Table 6 Initial and final set time measurements using the test procedure in AS 2350.

Binder Type	Ave. Initial Set Time	Ave. Final Set Time
70/30 Cement/Fly Ash	2 hrs. 23 mins.	3 hrs. 30 mins.
70/30 Cement/Slag	1 hr. 54 mins	3 hrs. 6 mins.
75/25 Cement/Fly Ash	2 hrs. 20 mins.	3 hrs. 43 mins.
40/60 Cement/Slag	3 hrs. 11 mins.	5 hrs. 15 mins.
Notes : 1. The Initial Set Time is when the penetrating needle encounters substantial resistance. 2. The Final Set Time is when the penetrating needle effectively stops penetrating the cement/sand/water mix.		

Both the Fly Ash blended cement [70/30 and 75/25 cement/Fly Ash] have an average initial set of approximately 2½ hours and a final set of approximately 3½ hours. The 70/30 cement/slag displayed slightly less initial and final sets of approximately 2 hours and 3 hours respectively.

However, the 40/60 Cement/Slag blended displayed significantly longer both initial and final sets of over 3 hours and over 5 hours respectively.

Practical Performance of Cement Blends in Stabilisation Works

The significantly longer time to initial set of the 40/60 cement/slag blend in comparison to the other common cement blends [approximately 40 minutes] and the even longer time to final set [over 1½ hours] are valuable advantages of this cement blend over the others in terms of quality and cost of stabilisation works. These extra time periods enable the material which is stabilised with this cement blend to be worked for a longer period than with using any of the other blends. This allows for more time to obtain the best compaction results and better shaping and trimming of the stabilised street before the “cement” begins to set. It also gives an extra safety period to overcome any problems that may arise during the works [e.g. delays due to breakdowns, broken services or weather problems, etc.].

Apart from the quality advantages, longer working times also allow for larger sections to be completed in one go thus allowing for increased productions and having cost saving advantages.

The strengths and flexural properties of all the common cement blends available, which were tested using Unconfined Compressive Strength and Resilient Modulus testing, are all comparatively similar.

The 40/60 cement/slag blend, apart from exhibiting longer set times, did show that once strength was developed it tended to develop more quickly. Again this is quite advantageous in practical terms in that as well as having a longer working time to work the stabilised material on the day of the works, at the end of the day the 40/60 cement/slag blend strengthens more quickly and thus reduces the likelihood of damage to the stabilised street overnight or during its early life by severe weather conditions or traffic prior to the wearing course being applied.

Environmental Considerations

Cement Stabilisation in itself is most beneficial to the community and the environment. Apart from its cost savings and savings in time and disruption, cement stabilisation in comparison to other more conventional methods of pavement construction and maintenance, greatly benefits the environment and the general community in which we live and work. By upgrading the properties of insitu or locally available inferior materials, cement stabilisation minimises the use of finite resources of good quarry products, minimises excavation and disposal of inferior road materials and minimises quarrying activities, truck traffic, energy usage and emission outputs.

GB [Blended] Cements have proven, in comparison to GP [Portland] Cement, to be even more cost effective and with their longer working times, more suitable to stabilisation works. However, using GB Cements, where some of the cement is replaced by Fly Ash and/or slag, greatly enhances the environmental benefits of an already significantly environmentally friendly process. The extra environmental benefits of using a GB Cement in lieu of GP Cement are two fold. Firstly, the manufacturing of Portland Cement contributes approximately 5% of global Carbon Dioxide emissions. By replacing 25% to 60% of the cement with Fly Ash and/or slag, the savings in emissions and energy alone to the environment are quite significant. Secondly, Fly Ash and Slag are themselves waste products from the burning of coal for power and from blast furnace production of steel respectively. Hence, the use of waste products to reduce detrimental environmental effects is a win win bonus.

Summary

Cement Stabilisation is a cost effective, quick and easy method of pavement construction and/or reconstruction with significant environmental advantages. The use of GB Cements in lieu of GP Cement increases the cost savings, quality and environmental benefits.

The selection of which particular GB Cement to use is dependent on a number of factors including: the local availability of Fly Ash and/or slag; the availability of blending facilities; relative costs; specific details of the stabilisation works [e.g. depth, size of job, traffic, construction constraints etc.] and the pavement design.

By testing in detail three different road making materials from Brisbane City Council which represented a reasonably wide range of variance for pavement materials, the performance properties for the four most commonly available GB Cements were able to be accurately assessed.

Since the Australian Standard referring to GB Cements is performance based using strength as the criteria, it would be expected that the particular GB cements commercially available would have similar strengths. The detailed testing of the different blended cements for Unconfined Compressive Strength and Resilient Modulus with the different host pavement materials, at different ages, reflected this.

Also, as one would expect from the chemical compositions of Fly Ash, Slag and actual Portland Cement, the test results indicated that Slag tends to be a slightly more efficient replacement product in a blended cement in terms of strength development. Hence, one can replace more of the Portland Cement in GB Cement with Slag than one could with Fly Ash. Hence, where the availabilities of Fly Ash and slag are not issues there may be economic advantages in using a high percentage slag blended GB Cement.

The results of the testing gave a clearer picture with respect to the timing of the strength development when using GB Cements. The extra working time available using all GB Cements in stabilisation work is a considerable benefit in terms of reducing costs further, through the ease of attaining quality levels and increasing practical production rates. Again, these advantages of GB Cement are slightly more pronounced for the higher slag content blends, e.g. 40/60 Cement/Slag.

The information gained in terms of Shrinkage was interesting in that it supported earlier evidence that the shrinkage is determined by the nature of plastic fines in the pavement material and that the addition of cementitious products actually reduces shrinkage. There was no significant variation in shrinkage behaviour between different GB Cements, therefore it can be concluded that shrinkage is not a factor in any selection criteria for the most appropriate GB Cement for stabilisation works.

The use of all GB Cements is of considerable benefit to the environment and the community. The replacement of some of the Portland Cement by Fly Ash or slag decreases the demand for the manufacture of cement with its subsequent environmental benefits of reduced limestone quarrying, energy consumption and carbon dioxide emissions. Since the replacement Fly Ash and slag are themselves waste products their use to replace the cement is a second significant benefit environmentally. Obviously, the higher percentage of cement that can be practically replaced in a GP Cement, the more benefit to the environment. Hence, while all GB Cements are of environmental benefit, there is slightly more advantage when using a higher slag blend such as the 60/40 Slag/Cement GB Cement.

In conclusion, the use of any GB Cement in cement stabilisation work is usually of benefit for a number of reasons. Some GB Cements have slightly greater benefits, for example the higher percentage slag blends. Through an understanding of the performance properties of GB Cements and assessing other factors including commercial viability, practicality and specific job requirements, an informed decision can be made on a suitable selection for an appropriate GB [Blended] Cement.

References

Australian Standard AS3972 for Portland and Blended Cements

Australian Standard AS3582.1 for Fly Ash

Australian Standard AS3582.2 for Ground Granulated Blast Furnace Slag

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