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Shrinkage Characteristics of Cementitiously Stabilised Basaltic Crushed Rock Mixed with Fine Grained Soil

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Summary: The aim of the project was to study the shrinkage properties of local stabilised pavement materials mixed with fine grained soils to facilitate their effective use in road construction and rehabilitation. Laboratory tests were undertaken using one conventional cementitious binder and two binders comprising industrial waste products. Locally available basaltic crushed rocks and clay were used as host pavement material and fine-grained soil respectively. Shrinkage tests were carried out following guidelines developed for concrete in different drying conditions. This paper described effect of binder types and quantities on the shrinkage behaviour of stabilised materials. It was observed that inclusion of fine-grained soil has significant adverse effect on the shrinkage characteristics of stabilised pavement materials for cracking. One-dimensional drying resulted in slow rate of drying but higher final shrinkage than three-dimensional drying.

NOTATION AND UNITS

l_0 = initial lengths of the specimens; l_i = measured length of the specimen; ε_{sh} = shrinkage strain.

BACKGROUND

In situ stabilisation using cementitious additives has become a common activity for rehabilitation of degraded road pavements in Australia. Several industrial waste products are also used in cementitious additives at present. Shrinkage is an important issue related to performance of the road pavements. A recent survey on cementitious stabilisation of Australian local roads has revealed that cracking due to drying shrinkage is a major issue associated with the usage of cementitiously stabilised materials in road pavement construction (Chakrabarti *et al.*, 2002). These cracks can deteriorate the pavement performance by reducing the overall stiffness of the pavement system, allowing water ingress into pavement base and subgrade, and by providing pathways for erosion of cemented materials. It follows that shrinkage potential and the possibility of shrinkage cracking should be considered from the early stage of mix design undertaken in the laboratory. There are no standard test methods to assess the shrinkage potential of cementitiously stabilised materials (CSM) at present. Therefore, the shrinkage of CSM is given special consideration in this investigation. Locally available crushed basaltic rocks and clay were used as host pavement material and fine soil respectively. One conventional cementitious binder and two binders comprising industrial waste products were used as cementitious additives. The performance of these binders was examined measuring drying shrinkage behaviours in different drying conditions. These factors were examined with respect to varying binder and fine soil contents.

LABORATORY EXPERIMENTS

Cementitious Binders

Binders used in these experiments include general-purpose cement (GP), general blended cement (GB), alkali activated slag (AAS). Cement consisting of Portland cement with no more than 5% of other mineral additions is classified as general purpose Portland cement (GP), and that consisting Portland cement and a quantity comprised one or both of (1) greater than 5% of flyash or granulated iron blast furnace slag, or both; and (2) up to 10% silica fume is classified as general purpose blended cement (GB) (Austroads, 1998). AAS used in this research is commercially known as "Roadment"(RM). GB cement and AAS include industrial waste products like fly ash and blast furnace slag, and are commonly used in Australia as slow setting binders (Serruto and Pardo, 2001). Advantages of such binders over traditional binders such as GP cement include greater working time and the beneficial use of waste products, which may otherwise end up as landfill. Main ingredients of the binders are discussed by Chakrabarti and Kodikara (2003). All binders were sourced from Blue Circle Southern

Pty Ltd of Australia.

Host Material

Crushed Rock

The selected host material was a Boral crushed basaltic rock sampled at Boral quarry, Deer Park in Melbourne, Australia. The sample was split and stored in 20 kg airtight plastic bags. Samples from each four bags were mixed and again stored in bags to minimise any variation between the samples. Grading curves are shown for the crushed rocks as well as for crushed rocks mixed with 6% and 15% fine soil, in Figure 1. The basic material properties are given in Table 1.

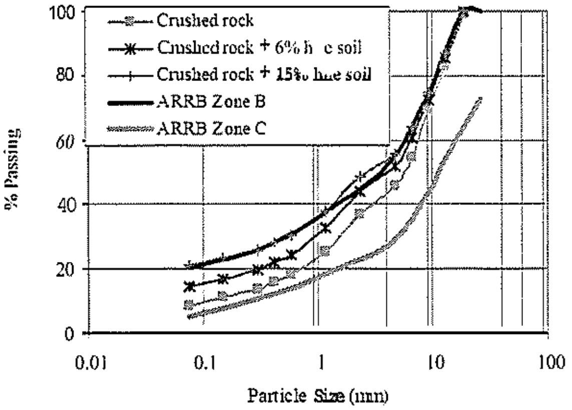


Figure 1. Particle size distribution

Material	Optimum water content (%) AS1289.5.1. 1-1993	Maximum dry density (kg/m^3) AS1289.5.1. 1-1993	Specific gravity AS1289.3.5. 2-1995	Linear shrinkage of fines (%) AS1289.3.4. 1-1995	Liquid limit of fines (%) AS1289.3.9-1991	Plasticity index (PI) of fines (%) AS1289.3.2. 1-1995
Crushed rock	9.8	2204	2.97	0.8	22	3
Fine-grained soil	27.5	1420	2.66	22	127	101
Crushed rock with (6%) soil	10.7	2220		8	33	14
Crushed rock with (15%) soil	11.85	2140		11	46	24

Crushed Rock and Fine-Grained Soil Mixtures

The fine-grained soil was a locally available residual basaltic soil sourced from excavated material between 2 m to 8 m depths at the Aquatic Centre at Werribee, Victoria, Australia. Mixtures of crushed rock and fine-grained soil were made by adding 0%, 6% and 15% (by dry weight) of fine-grained soil to the crushed rock. These mixtures were almost within the range (ARRB Zone B and C) recommended by Austroads as shown in Figure 1. The basic material properties of the fine-grained soil and the mixtures are given in Table 2.

Mix Preparation

The crushed basaltic rock and the fine material were mixed in dry condition and then mixed with potable tap water to achieve the required optimum moisture content and even distribution within the mix. For the linear shrinkage (LS) test as per AS1289.3.4.1-1995, part of the rock materials passing through 425-micron sieve was mixed with fines and water. The binder was then added and was mixed for further two minutes. The mixture was kept in a container, covered to prevent moisture loss for 2 hours prior to compaction. For specimen with fine soil only, fine soil was mixed with water and cured for 24 hours before compaction to achieve uniform mixing. Specimens were prepared with standard compactive efforts, proportional to the maximum dry density corresponding to optimum moisture content for all types of specimens.

Test Methods

Drying shrinkage tests were performed with specimen of dimension 75 mm (wide) x 75 mm (high) x 280 mm (long) as per methods in Australian Standard AS 1012.13-1992 (Standards Australia, 1992). The test method satisfied the following conditions:

(a) The dimensions of the specimen should be relatively large compared to nominal maximum aggregate size of the material, so that a representative portion of the material is used in the test.
(b) The shrinkage of stabilised soil should be measured in a plane normal to the direction of compaction to reflect the field condition.

It should be noted that drying shrinkage test is an indicative test only and may not directly relate to the conditions that exist in the field. The known quantity of mixture as per maximum standard dry density was compacted in two layers into a rectangular steel mould measuring 75 mm (wide), 75 mm (high) and 280 mm (long). Standard Proctor hammer with maximum cross sectional dimension of 50 mm (65 mm including the guide) was used to compact the material. A clear gap of 5 mm between the inner face of the mould and outer face of the guide of the hammer facilitated uniform compaction with compaction energy proportionate to the standard compaction. A steel tamping bar was used for compaction of local areas and for obtaining a level surface. For stabilised mixture, two gauge studs were placed centrally at the end sections during compaction to facilitate shrinkage measurement. For specimen prepared with clay only, no gauge studs were used. Specimens in duplicate per set were cured for 24 hours at 90% or above relative humidity (RH) and air temperature of 21°C to 24°C. Subsequently, specimens were dried in a controlled environment with 50% RH and air temperature of 22°C. For these drying shrinkage experiments, two types of specimens were used: (1) drying from only one face simulating one-dimensional (1-D) drying conditions and; (2) drying from all faces simulating three-dimensional (3-D) drying conditions. The one-face drying was achieved by covering five sides with wax and plastic film, but allowing drying from the top surface, measuring 75 mm x 280 mm. In the case of three-dimensional drying, all the six faces were exposed for dying. Specimens made with only fine soil were dried at 50°C temperature.

The initial lengths of the specimens l_0 (mm) were measured as per AS 1012.13-1992 (Standards Australia, 1992) using a horizontal length comparator with a digital micrometer, which had a least measurement of 0.001 mm. For specimen prepared with clay only, lengths were measured by standard ruler. The micrometer reading was initialised with a metal reference bar prior to measuring the specimen shrinkage. Specimen lengths, l_i (mm) were recorded at various times up to 90 days with gradually increasing time intervals. The specimens were kept in a controlled environment of 22°C and 50% relative humidity during the measuring period. Shrinkage (ε_{sh}) at any time in microstrain was determined as follows:

$$\varepsilon_{sh} = \frac{(l_t - l_i) \times 10^6}{l_0} \qquad (1)$$

where l_0 and l_t respectively are initial length and final length at a given time.

For LS tests, mixture of rock materials passing through 425-micron, fine soil, water and binders, corresponding to the liquid limit was placed in a mould with semicircular cross section, measuring 250 mm long and 25 mm diameter. Specimen within the mould was air dried for 24 hours and then dried in an oven at 105° C. The linear shrinkage was determined as the total change in length presented as a percentage of the original length.

RESULTS AND DISCUSSION

The results of the shrinkage tests for drying in three directions are presented in Figure 2. On each graph, the shrinkage as a function of time is shown for different types and quantities of binders and fine contents. The results clearly show that the rate of drying shrinkage is relatively rapid in early days. Shrinkage becomes faster and greater with increases in fines content. Shrinkage becomes steady after 21 days in almost all cases for crushed rock only and after 7 to 12 days for crushed rocks mixed with fines. It may be argued that the inclusion of fine material resulted in finer pore size distribution in the mix. Shrinkage takes place mainly due to loss of moisture from finer pores. The shrinkage in specimen with GB cement decreased with increase in binder contents. For GP cement shrinkage increased with increase in binder content for crushed rock only. It happened due to increase in calcium silicate hydrate gel content in the mix. However with inclusion of fines, the shrinkage was dominated by the presence of the fines and GP cement only neutralised the effect of reactive fines. Thus shrinkage decreased with increase in binder content. Similar behaviour was found for **AAS.** It is interesting to note that AAS displayed significantly low shrinkage in all the cases in comparison with GP cement and GB cement. Serruto and Pardo *(7)* also inferred similar trends on the basis of relatively simple linear shrinkage tests (described previously) conducted on the fine component only.

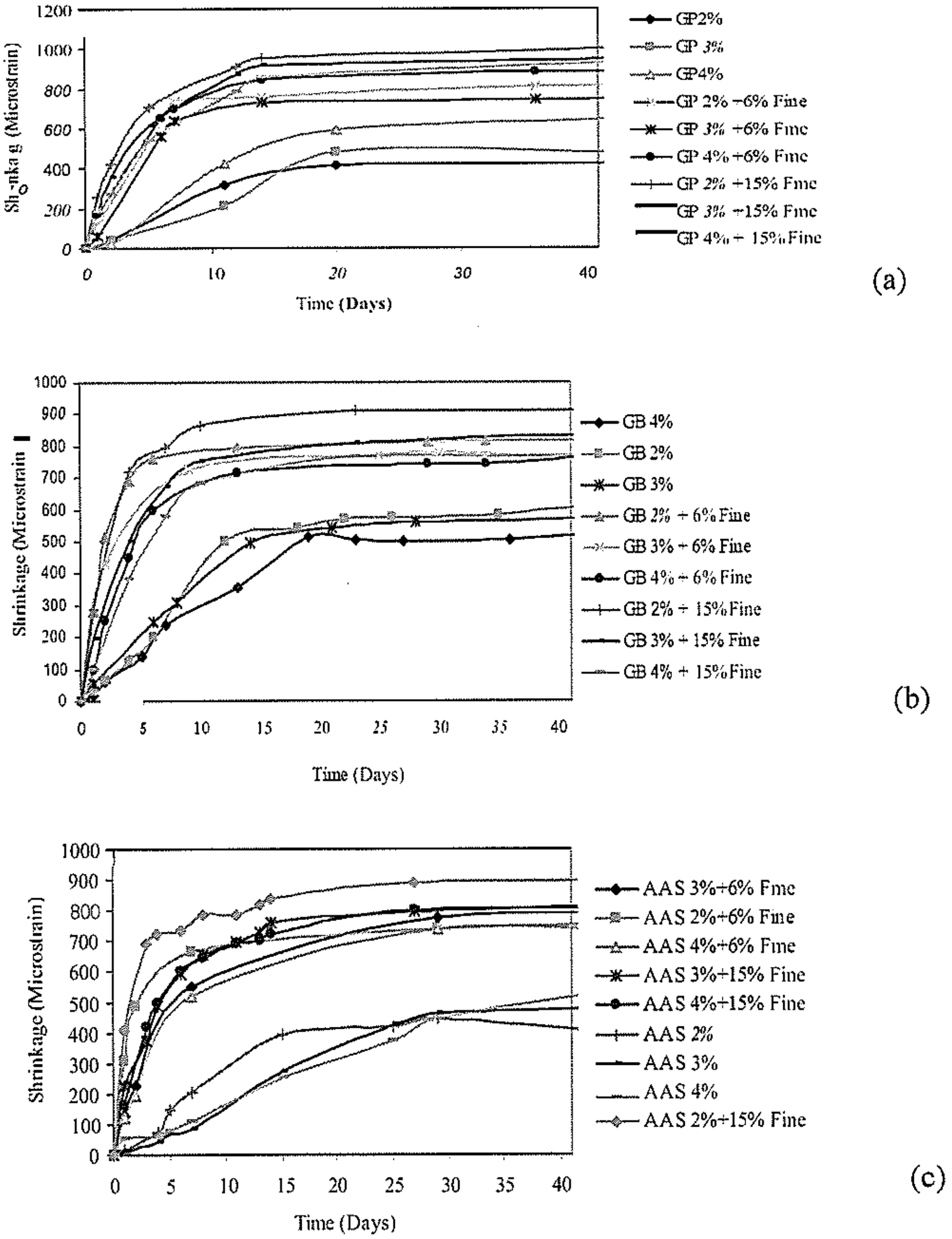


Figure 2. Shrinkage with time for (a) GP cement (b) GB cement (c) AAS

Figure 3 shows relationships between LS determined as per AS1289.3.4.1-1995 and shrinkage of the prism for various GB binder contents as determined in this investigation. Similar relationships were found for other two binders as well. Figure 4 shows relationship between shrinkage and plasticity of the raw materials. It follows that simple LS or PI tests may be rough indicators of shrinkage of stabilised mix. It may be noted the shrinkage measured in this investigation corresponds to laboratory conditions that may substantially be different in field situation.

Shrinkage behaviour for 1-D drying was different from 3-D drying. Relationships between drying shrinkage and drying time for various binder and fine contents for GB cement are shown in Figure 5(a). 1-D shrinkage occurs much slower in comparison to 3-D drying. For example 1-D shrinkage stabilises after 60 days in comparison to about 20 days for 3-D drying for crushed rock.

But ultimate shrinkage was found to be higher on 1-D drying. For example shrinkage for 1-D drying was about 70% and 40% higher than 3-D drying for crushed rock without and with fine grained soil respectively.

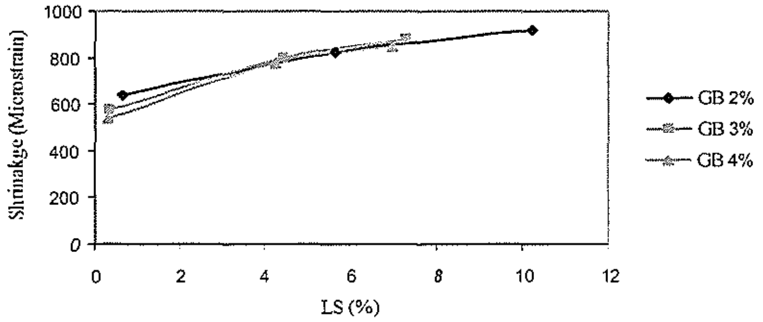


Figure 3. Relationships between shrinkage for prism with LS for GB cement

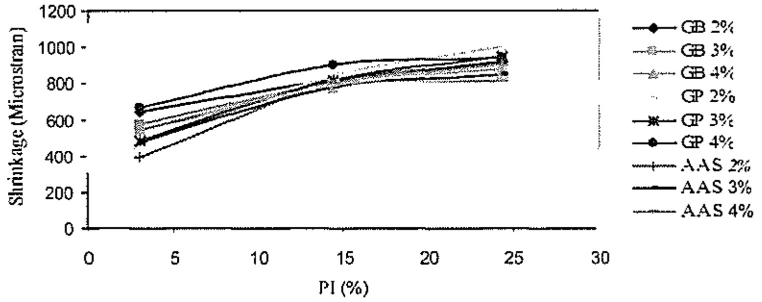


Figure 4. Relationships between shrinkage and PI

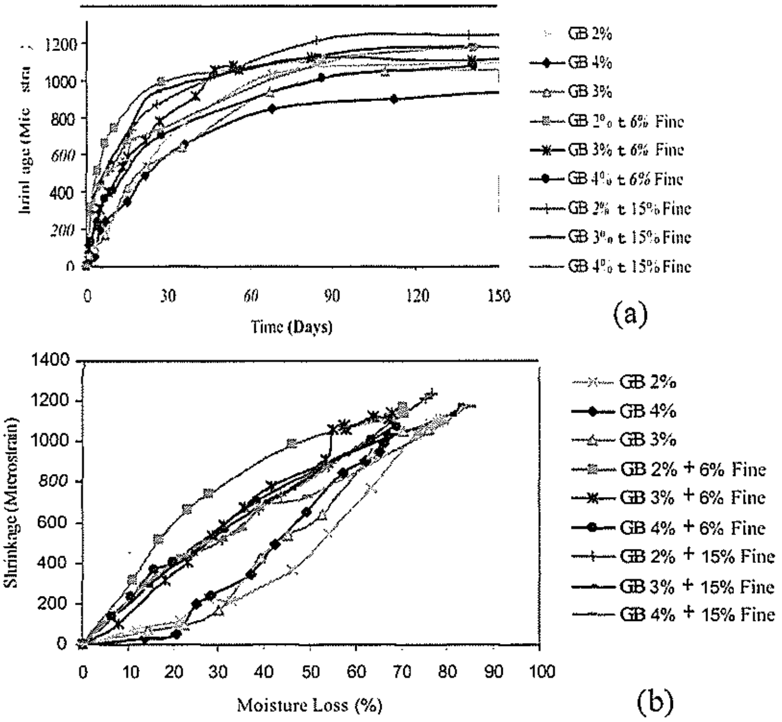


Figure 5. Relationships between (a) 1-D shrinkage and drying time (b) 1-D shrinkage and moisture loss

Shrinkage for 1-D drying also became faster and greater with increase in fine content in the mix. This may be clear from Figure 5(b). For crushed rock, initial moisture loss happened from larger pore causing relatively small shrinkage. But with fines soil, shrinkage is almost proportional to moisture loss and took place from very beginning of drying. Similar trend were available for GP and AAS. It may be relevant to mention that if moisture loss can be predicted at any environmental conditions, resulting shrinkage can also be indicated from such relationships. To investigate this type of dissimilarities in two types of drying conditions, similar tests were done with fine oil only. Figure *6* shows shrinkage with time for drying in both one and three dimensions. It is evident that shrinkage in 1-D drying was slow but about 40% higher than 3-D drying.

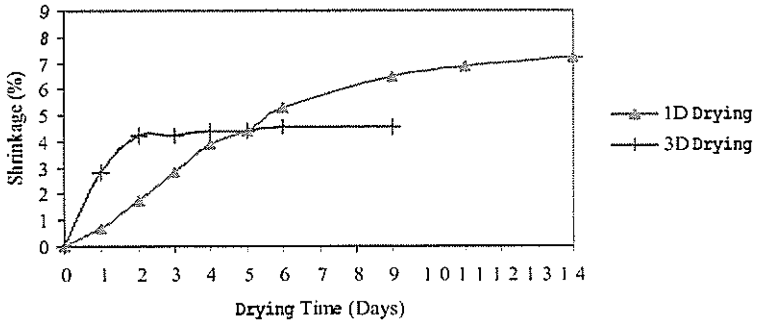


Figure 6. Relationships between shrinkage and drying time

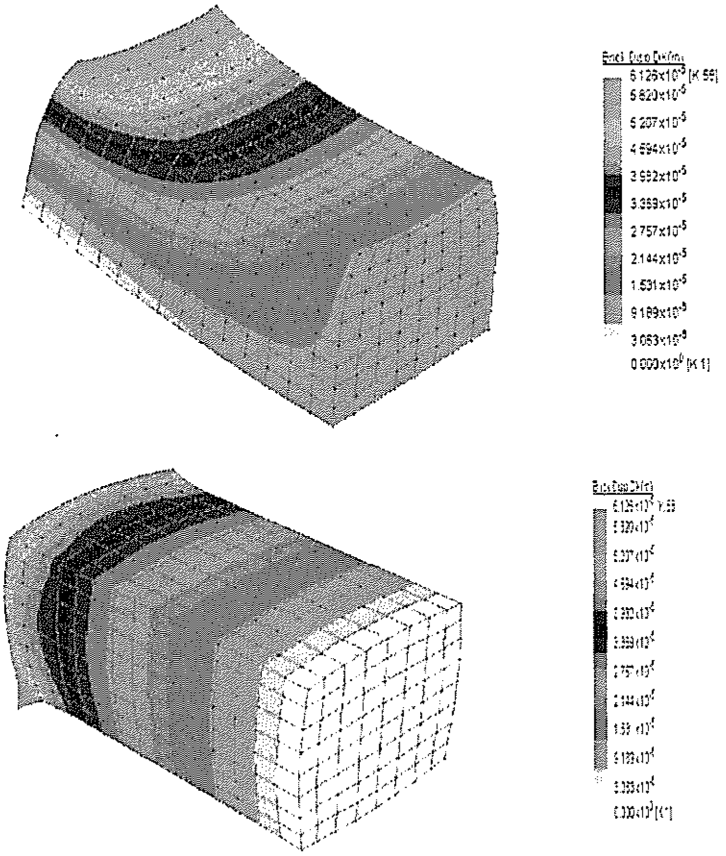
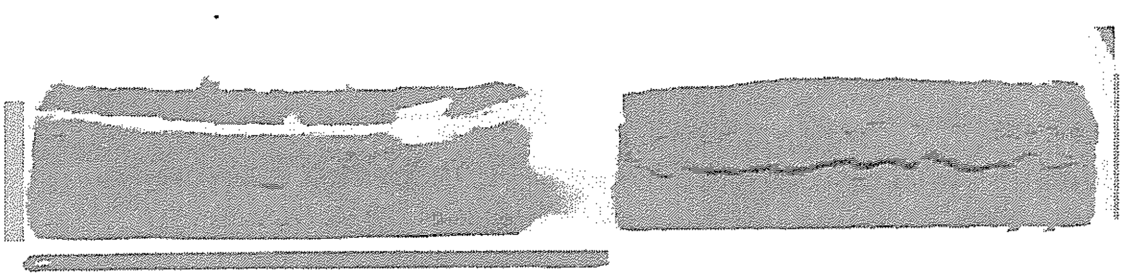


Figure 7. Deformation pattern after 1 day (a) one dimensional drying (b) three dimensional drying

To examine the mechanism behind the difference in the shrinkage patterns for two different conditions of drying, 3-D finite models were built with STRAND 7 program. Moisture content profile in the specimen at any stage of drying was determined by using non-linear diffusion equations as described by various authors (Akita et al., 1997, Chakrabarti and Kodikara, 2001). Equivalent stresses due to moisture potential corresponding to moisture contents at various nodes were applied. Figure 7 shows the deformation patterns for 1-D and 3-D drying of one day. It was clear that shrinkage was distributed equally at all the faces for 3-D drying whereas it was concentrated on the drying surface for one-dimensional drying. For one-dimensional drying, specimen appeared to undergo curling. This mechanism is currently being investigated for CSM, but has been examined in some detail for reactive soil drying (Kodikara *et al.*, 2003). Figure 8 shows difference in drying shrinkage and cracking pattern for specimens prepared with fine soil. The specimen undergoing 1-D drying experienced delayed but higher shrinkage, no cracking but curling. But for 3-D drying specimen, shrinkage developed faster and gained less final shrinkage. The specimen also experienced cracking at later stage, as shown in Figure 8(b).



(a) (b)

Figure 8. Drying for specimen prepared with fine soil (a) one dimensional drying (b) three dimensional drying

CONCLUSION

A laboratory study was conducted to evaluate the relative drying shrinkage of crushed basaltic rock mixed with fine-grained plastic soil and stabilised with different types and quantities of cementitious binders at various drying conditions. Based on the analysis of laboratory test results, a number of observations were made. Shrinkage from 1-D drying, which is similar to pavement conditions, is slow but higher than shrinkage due to 3-D drying. Inclusion of fine material resulted in greater and faster shrinkage in all cases. The shrinkage was generally less for AAS than for both GP cement and GB cement. Simple LS and PI tests for fines only may be used as a preliminary indicator of shrinkage, particularly for comparative purposes, but are not adequate to quantify the shrinkage strains that may occur in real mixes. Shrinkage of pavement materials in any environmental conditions may be predicted from prediction of moisture profile in the specimen and using either relationship between shrinkage and moisture loss or using stress application corresponding to moisture potential in the specimen. The test results indicated that the use of slow setting binders with industrial waste products such as fly ash and slag could be more effective in stabilisation of basaltic rock materials with or without fine-grained soils than traditional binders like GP cement. Further research is underway at Monash on these topics.

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