A new approach to determining working time for road stabilisation for all binder types

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ABSTRACT

The working time principle was developed by the NSW Roads & Traffic Authority in the early 1990s to assist cement suppliers to predict in the laboratory, the time it will take for cementitious binders to set in the field before they can be successfully compacted.

In NSW, the process have been developed as a research tool using density and UCS testing as a basis for estimating the duration that a cementitious binder could be mixed and left uncompacted in the field before performance is reduced. Until recently, no test method in NSW had emerged from the research work of the 1990s, and consequently there was limited opportunity to use a better binder by the contractor seeking an alternative tender bid for the project.

Five years ago VicRoads published a test method based on their research work in Burwood East (Victoria). Whilst the outcomes of their research varied, this technique has since been used in NSW with some success.

As both NSW and Victoria have different approaches to testing working time and each has their own limitations, a new approach based on tests carried out so far was required. This paper examines the current test methods and outlines a new approach for practitioners to consider. In addition, the paper explores whether this new approach may be applicable to all types of stabilisation binders.

INTRODUCTION

The working time concept was developed by the Roads & Traffic Authority, NSW (RTA) in the early 1990s to provide guidance to contractors on the practical duration of mixing, compaction and trimming of insitu stabilisation. A key determinant in successful deeplift insitu stabilisation was the significantly longer working times provided by slow-setting binders, such as slag/lime; when compared to the short working time of GP cement.

The decision to determine working time was made in order to provide binder supplier companies with a point of comparison when developing new slow setting binders. A longer working time was subsequently specified in company promotional materials which helped contractors increase productivity levels and reduce construction risks in the field.

Working time is a function of the pavement material, binder type and also the ambient conditions, with colder weather slowing the hydration process. At this stage, the binder application rate does not appear to impact on the working time duration.

The current application of working time is limited to bound pavements as defined by Table 1. It is very unlikely that a designer or contractor would reach the working time limit for modified materials before compaction and trimming was completed.

Table 1: Stabilisation may result in unbound, modified or bound materials (Austroads, 2006).

Category of stabilisation	Indicative laboratory strength after stabilisation
Subgrade (subgrades and formations)	$CBR^1 > 5\%$
Granular (subbase and basecourse)	$40\% < CBR^1 < +100\%$
Modified (basecourse)	0.7 MPa $< UCS^2 < 1.5$ MPa
Bound (basecourse)	$UCS^2 > 1.5$ MPa
NOTES: 1. Four day soaked Californian Bearing Ratio (CBR). 2. Unconfined Compressive Strength (UCS) values determined from test specimens stabilised and prepared using standard compactive effort, normal curing for a minimum 28 days and 4 hour soak conditioning.	

Recent experience in the use of slow setting binders in NSW and Victoria, has shown that further improvements could be made to the test method used to determine working time. A national approach to the development of a unified test method is warranted.

This paper reviews the current test methods specified by RTA and VicRoads, and provides recommendations for the development of a new Australia wide test method.

CURRENT DEFINITION

Working time is defined in terms of a laboratory determination and field compliance. The definition presented in the Austroads Guide to Stabilisation (Austroads, 1998) is:

> The nominated working time for any proposed mix, shall be the lesser of the working time for the maximum dry density (MDD) and unconfined compressive strength (UCS).
>
> The working time for maximum dry density is defined as “the time measured from the commencement of the addition of the stabilising agent to the compaction of the stabilised material, which corresponds to 97.0% of the mean value of three determinations of maximum dry density, for samples compacted one hour after incorporation of the stabilising agent.”
>
> The working time for unconfined compressive strength is defined as the time measured from the commencement of the addition of the stabilising agent to the compaction of the stabilised material, which corresponds to 80% of the mean value of three determinations of UCS, for samples compacted one hour after incorporation of the stabilising agent.

Figure 1 shows the relationship described above in diagrammatic form. The Austroads guide notes that all samples are cured in a loose condition in airtight containers at 23°C ± 2°C and are not soaked (preconditioned) prior to testing. In addition, the RTA permits the use of 7-day accelerated loading according to RTA test method T131 (RTA, 2000).

VicRoads carried out a large research program several years ago to increase the usage of slow setting binders for insitu stabilisation and found that the use of the MDD test could be ignored for the laboratory determination of working time (Yeo, 1997). They defined working time as (VicRoads, 2000):

> The time available, to the nearest hour, to fully compact for a standard crushed rock base material stabilised with the a cementitious binder, to achieve reach a value of 90% of the Unconfined Compressive Strength (UCS) determined for the stabilised material when compacted after standing storage for one hour at the specified temperature.

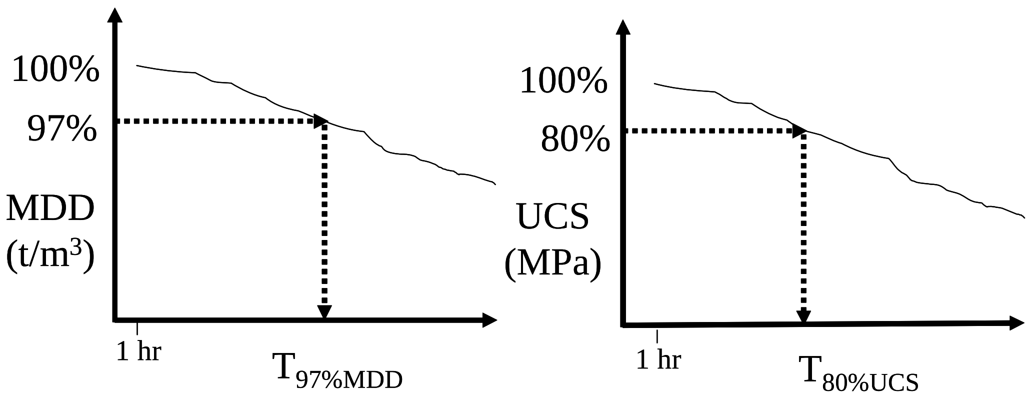

***Figure 1*:** The RTA definition is based on testing the material for density and compressive strength.

Unlike the RTA, VicRoads allowed two temperature ranges for curing the sample over a 7 day period and hence modified the criteria to 90% rather than 80% of UCS[1]. The specified curing temperature for the nominated construction period is either:

May to September	10° to 15°C
October to April ...	20° to 25°C

The different curing temperatures were permitted as the cooler pavement temperatures experienced in many parts of Victoria should allow for the slower reaction time of the cementitious binder. During cold weather and if the road has to be open to traffic at the end of shift, a cementitious binder with a short working time may be more appropriate to prevent overnight damage to the surface.

Queensland's Department of Main Roads have used the wet density test as a measure of working time and report that this approach is simple to use (Ramanujam, 2004).

It has also been reported that work in Brisbane has used initial and final set time measurements using AS 2350.4 to gauge the duration of working time for four types of binders and several quarried materials (Smith, 2003).

Other regions of Australia have not yet developed a definition of working time and there are no known overseas test methods for working time of cementitious binders.

In terms of field compliance, the working time is defined as the time between when the binder is mixed and the completion of primary trimming of the stabilised material. With two binder spread runs, the clock starts during the first mixing pass. Working time does not preclude the use of final trimming, however most contractors will strive to complete all trimming operations before opening the road to traffic.

In RTA R73 and R75 specifications (RTA, 2002a & 2002b), the working time presented in specifications may limit the nominated working time to 12 hours to ensure that construction is completed within the same day or shift. However if there are unforseen circumstances such as an equipment breakdown or a traffic accident, compaction may be completed the next morning provided that the working time for the binder is still applicable for the project material.

BINDERS

The typical working time for various binders is listed in Table 2, with GP cement assigned a working time of 2 hours. Many of the cement based binders do not provide substantial increases in working time as shown in Table 3 (also see Figure 2).

[1] Experience indicates that the 7-day strength is about 75% of the 28-day compressive strength for cementitious binders.

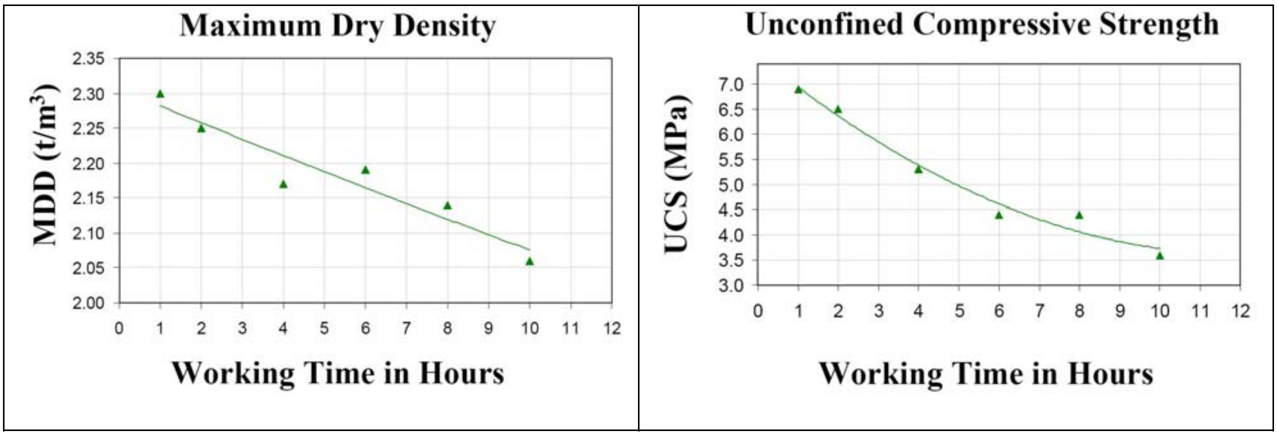

Figure 2: Working time charts for MDD and UCS with working times of 3.25 and 2.5 hours respectively with 4% binder content (BCSC, 2005). Tested to RTA R75 specification.

As noted previously, VicRoads has nominated maximum working times for various binder types for two periods of the year as shown in Table 3. This allows the road project to be priced for either the cold or warm season, and should the project be delayed, the contractor is permitted to change the binder[2] to meet the allowable working times for the season. VicRoads also permits the May to September maximum allowable working times to be applied if the ambient temperature within the period from October to April on any day is less than 15°C. This approach should not be limited to Victoria, as other regions in Australia experience similar cold temperatures, although only for a few months.

Table 2: Working time for typical cementitious binders under normal curing conditions.

Binder	Product name	Working time (hours)
GP cement	-	2
Cement/Slag (60:40)	SSC60	2 to 3
Cement/Slag (40:60)	SSC40	2 to 3
Slag/Lime/FA (50:30:20)	532 Slag T Blend	5 to 10
Cement/FA (75:25)	Road Pozz	2.5 to 3
AAS	Roadment	> 8
Slag/Lime (70:30)	70 Lime Blend	4 to 10
NOTES: 1. Slag refers to Ground Granulated Blast Furnace Slag to AS 3582.1 2. Lime refers to hydrated lime 3. FA refers to black coal fly ash to AS 3582.2		

The working time test method is also applicable for chemical binders that retard the hydration process of cementitious binders. These chemical binders are usually applied in the mixing water and in some cases, provide the opportunity to trim the road the day after mixing.

It has also become apparent that foamed bitumen stabilisation with a secondary binder, such as lime, may cause a ‘cementing’ action at the surface of the stabilised layer within the first 12 hours and make it difficult for the material to be trimmed the next morning (AustStab, 2005). Therefore, whilst it is recognised that foamed bitumen may be remixed up to 7 days after first mixing, the material should be trimmed during the same shift (AustStab, 2006a). Although, there have been no reports on working time limits for foamed bitumen, the approach proposed in the paper may be applicable.

Other binders such as chemicals (Austroads, 2006) used in stabilisation, generally do not form bound materials and the delay in compaction is unlikely to be significant unless wet weather and the need to traffic the pavement may result in early distress of the material. For lime stabilisation, it is common to allow the

[2] This process is carried out through a variation in the contract price.

material to be remixed in the field after the addition of the lime, and this again would not require a working time limit (AustStab, 2006b).

Table 3: Maximum working times for binders permitted on VicRoads projects (VicRoads, 2005).

Cementitious Binder	Maximum Allowable Working Time (hours)	
	Construction between October and April	Construction between May and September
Rapid Setting GP Cement	2	3
Medium Setting GB Cement Cement/Slag blend (50% to 60% cement content) Cement/Fly ash blend (70% to 80% cement content) Cement/Slag/Fly ash blend (55% to 65% cement content)	3	5
Slow Setting Slag/Lime blends and other supplementary cementitious blends	8	12
Lime (Hydrated and Quicklime)	12	24

EXISTING TEST METHOD

VicRoads developed the first published test method titled *Determination of the maximum allowable working time for a cementitious binder* (VicRoads, 2000). This test method consists of preparing a stabilised material and delaying compaction of the material into cylindrical samples for a period of time to reflect different working times in the field.

Compaction of the samples is carried out to standard[3] or modified compactive effort and cured at normal temperatures for a period of 7 or 28 days. RTA technicians commonly cure samples using elevated temperatures (ie 65°C) for 7-days duration to establish a comparative 28-day UCS value for the stabilised material.

Due to the laboratory costs, the large size of samples needed, and the laboratory operating hours, the number of time periods after 1 hour required for delayed compaction is 4[4] (see Figure 3). Although these five values provide an opportunity to plot the data (see Figure 4), results can scatter leading to a degree of difficultly selecting a line of best fit (see Figures 5 and 6). In both cases, the curve does not go through the reference point (ie at 1 hour) which could mislead the designer into selecting the incorrect working time value.

The RTA does not have a dedicated test method for working time and is currently developing a materials test method for the determination of working time to replace the definition placed in the deeplift insitu stabilisation specification. This will allow the use of normal and accelerated curing methods.

[3] Austroads and AustStab preferred method is standard compactive effort.
[4] VicRoads test method RC 330.02 suggests samples compacted at delay times of 2, 4, 8, 12 and 24 hours.

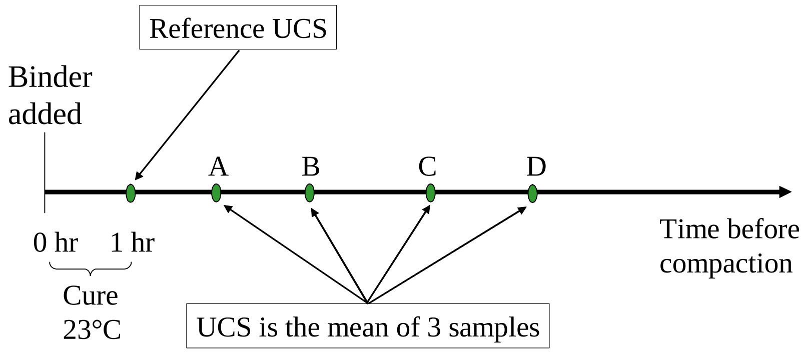

Figure 3: Timing of the compaction (standing time) of the samples after the commencement of mixing the binder and pavement material.

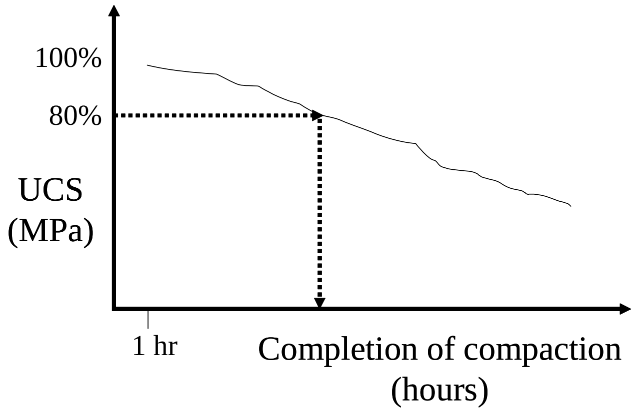

Figure 4: Ideal UCS versus time results.

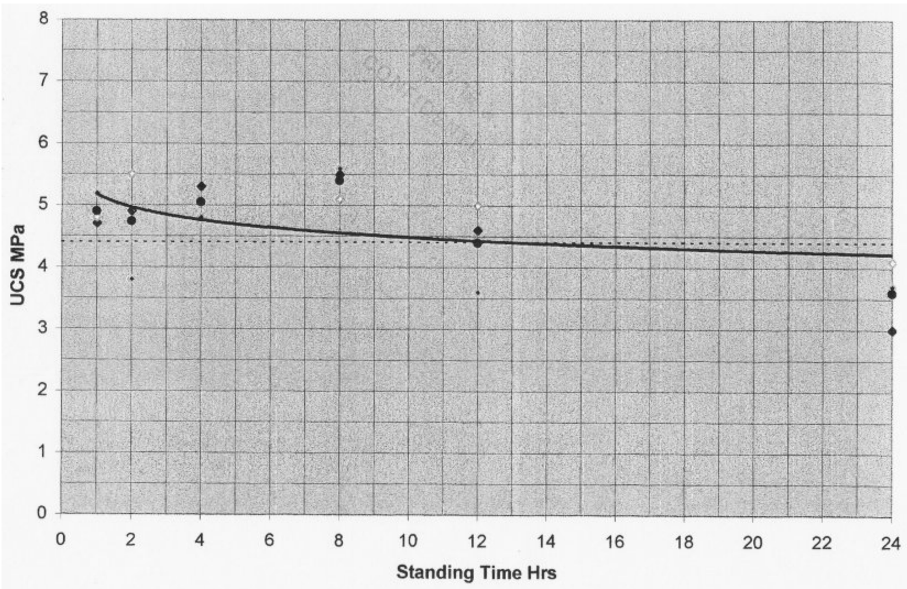

Figure 5: Plot of UCS versus standing time for a slow setting binder and crush rock showing the 'flatness' of the curve.

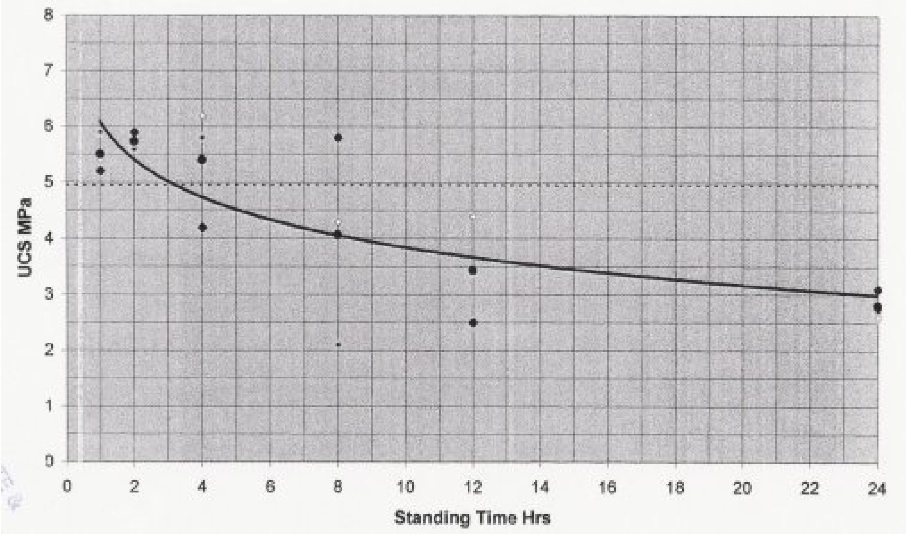

Figure 6: Plot of UCS versus standing time for a slow setting binder and crush rock.

PROPOSED TEST METHOD

General

Although the working time test has been widely used in NSW and Victoria for almost a decade, ongoing application of the test to the new generation of slow-setting binders has demonstrated some short comings or uncertainties with the test protocols. This includes aspects such as:

- test materials
- sample preparation
- curing method – temperature & duration
- number of samples
- unconfined compressive strength
- maximum dry density
- criteria for working time

If the test is to be improved, these short comings need to be identified and further research undertaken to resolve them.

Test materials

The intention of the existing test method is to use pavement materials from the field and subject the test sample to similar environmental conditions. However there is also a sound rationale for using a referenced quarry material rather than a pavement material that in reality is often not homogenous in the field. For a region such as a Victoria, the reference material could be expanded to six commonly found road base materials that have been used for road making over the last 50 years.

At the moment there is no universal reference pavement material for Australia and a simple solution would be for each region to have a specified reference material. In addition, slow setting binders are known to react differently with various levels of Plasticity Index (PI) and it would therefore be preferable to use low and high PI reference materials in the test program. Suggested quarried pavement materials in various regions are listed in Table 4. The lack of a suitable reference material in NSW has created many difficulties for designers and binder suppliers selecting a suitable test material for the development of better binders.

Table 4: Suggested reference pavement materials to be used in the determination of a nominated working time.

Region	Reference Material	
	Low PI	High PI
Victoria	Class 2	Class 3
Queensland	Type 1	Type 2
South Australia	Para Hills	-

Sample preparation

The existing test protocols use the Austroads approach for UCS testing which is to mould samples using a nominal 100 by 100 mm cylindrical mould with standard compactive effort (Austroads, 2002). The Optimum Moisture Content (OMC) and MDD of the parent material are required as a reference point and it is anticipated that the sample will be compacted at OMC.

When using marginal materials, ‘poor’ particle size distribution or the breakdown of weak stones during compaction may change the maximum density resulting in lower than expected density measurements. The weak stones may also lead to lower UCS values as the stones fracture before the matrix holding the stones.

It is suggested that each sample be prepared to the OMC of the untreated material and compacted using standard compactive effort. The moisture used in cement hydration is likely to bring the moisture of the sample back to similar conditions in the field where the contractor will invariably mix the binder and pavement material drier of the OMC.

Curing method and duration

Curing of samples for UCS or other tests is normally carried out at standard laboratory controlled temperatures. However if the duration of curing is short (ie about 7 days or less) and the curing temperatures are low, there is increased potential for variability in a pair of cylinders. A better way of minimising the impact of the variation in strength, is to cure the sample to 28-days or use the RTA 7-day accelerated curing method (RTA, 2000). At this stage, there appears to be no adverse affect from the higher temperatures (ie 65°C) on cementitious blends.

It is suggested that for cooler regions of Australia (i.e. ambient temperatures less than 5°C), it is acceptable to cure the sample at 10° to 15°C. In this instance, no accelerated temperature curing is considered appropriate for the curing period. The minimum curing period for low temperatures should be 28 days.

Whilst it is recognised that designers need to minimise the time it takes to establish the appropriate binder in the laboratory, such that the work can proceed; taking short cuts in reducing the curing regime should not be considered.

Number of samples

Are pairs of samples sufficient or should a minimum of three samples be tested at every standing time? There are generally adequate guidelines to handle larger differences between pairs for compression testing, however since this test has a long duration and low strength values, it is suggested that at least three samples are used for each standing time.

At the start of the sample preparation program, each sample requires about 15 minutes preparation time to place and compact in the moulds. When three samples are used, the duration between completion of the first and third sample is about 30 minutes. Using a 28-day curing process and slow-setting binders, the duration in the preparation of samples between the first and third sample is unlikely to reduce the average value of the reference UCS.

The use of three samples allows for better identification of outliers compared to when pairs are used as one sample may be an outlier (as shown in Figure 5) but this cannot be confirmed with only two samples. When an outlier differs by more than 30% of the standard deviation from the value of the middle triplet, it is common to delete this sample from the analysis, so that the average of the two other samples can be used to locate the line of best fit.

Unconfined Compressive Strength

Compressive testing using cylinders with a 100 mm diameter by 100 mm height mould (nominal dimensions), is an acceptable approach provided that the particle size distribution is uniform and the maximum particle size is less than 19 mm. Other sizes have been considered by Austroads but it was agreed to remain with the current practice (Austroads, 2002).

Maximum Dry Density (MDD)

Experience to date indicates that the MDD test is likely to cause greater variation in results than a UCS test due to:

- the hydration process from the cementitious material commencing during the waiting period
- bonds being formed between the cement and pavement material and this will change the density and particle sizes
- the material moisture content varying in the sample based on how the treated material 'rests' on the laboratory table[5] (VicRoads, 2000).

In addition, the moisture level of the pavement material in the field can vary due to the climatic conditions immediately prior to the work. This limitation on measuring moisture with any degree of accuracy in the field just before and during the work, leads to suggest that the MDD approach to working time is not productive.

On site, the use of the 'hand squeeze' test[6] will typically allow the operator to confirm that the moisture content is on the drier side of OMC, which for many decades, has been shown to provide adequate performance results for insitu stabilisation based on compliance records from contractors.

The use of the MDD is therefore not recommended to determine working time.

Criteria for working time

Under the proposed protocol, three values of UCS are measured at different time intervals. The line of best fit can be taken as a line between the data points or as a logarithmic curve. A straight line approach may not be conservative as the curve will normally take a lower value (or path). When determining the trend curve it is essential to use the initial reading at 1 hour as the starting point for the curve.

RECOMMENDATIONS

To ensure a robust test procedure, the following recommendations should be considered:

- Prepare the sample to OMC of the untreated material to ensure that after hydration, the sample's moisture content is on the dry side of OMC.

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[5] Anecdotal observations comparing the MDD results from the treated material spread over the laboratory table versus left in a heap.
[6] The hand squeeze test is a simple measure of the cohesiveness of the soil and the test is used by the contractor as a guide to the insitu moisture content after mixing water into the pavement material.

- The average of a minimum of three samples is required for the reference UCS test and the average of a minimum of 3 samples for the UCS at all subsequent standing times. When outliers[7] have been identified in the sample set, the outlier should be deleted in the determination of the average value.
- The reference time is 1 hour after mixing the binder.
- The standing times are 2, 4, 8, 12, 18, 24 and 48 hours.
- The curing time is either 28 days standard curing or 7-days accelerated curing[8], and the samples should not be soaked prior to testing.
- If cold weather site mixing is anticipated, the curing temperature should be reduced to 10° to 15°C and cured for 28-days.
- Exponential curves are typically selected for the trend line, with the curve going through the reference point.

CONCLUSION

The introduction of deeplift insitu stabilisation in the 1990s presented two new challenges:

- the need for the contractor to spread and mix the binder, and compact the stabilised material in sufficient time to ensure that maximum density was reached before the material bonds, and
- the need to trim the pavement to achieve higher ride quality than had been sought in the past.

These goals were met by the use of slow setting cementitious binders and heavier compaction equipment. As a number of cement producers were keen to supply these binders, they needed a test method to prove their performance in the laboratory before being specified in the field. By the late 1990s, there were more than forty products competing in this market.

The ability to predict working time in the laboratory paved the way for the formation of a new test method. This first generation of the test method was expensive and time consuming and has had little ongoing success apart from being a research tool. VicRoads made some refinements to the RTA test method in the late 1990s as outlined in this paper.

Both the designer and contractor want a common and transparent contracting process, and this has resulted in the need to refine the test method and make it suitable across Australia. This paper outlines some key factors for consideration in the development of a new Austroads test method.

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[7] An outlier occurs when a result is greater than 30% of standard deviation of the middle triplet.
[8] Accelerated curing is oven dry at 65°C.

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