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Mix Design of Cementitious Basecourse

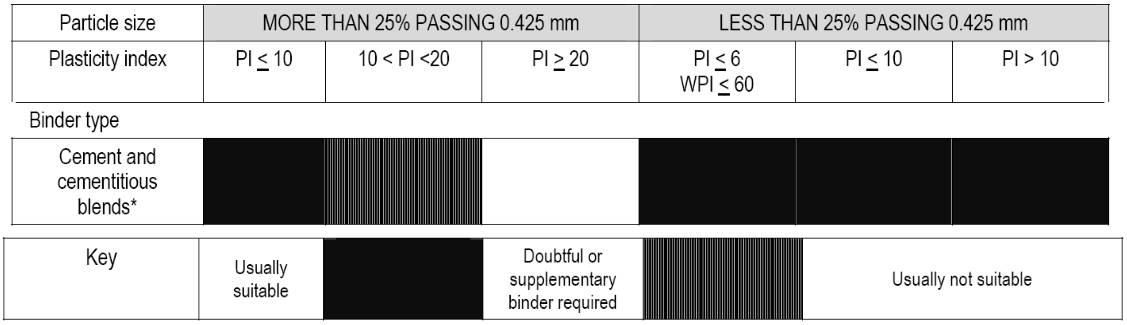
Yang Sheng Yeo[1], Peerapong Jitsangiam[2] and Hamid Nikraz[3]
[1]PhD Researcher of Curtin Pavement Research Group, Curtin University
[2]Lecturer of Civil Engineering, Curtin University
[3]Professor of Civil Engineering, Curtin University

Synopsis: Selecting stabilisation mix designs for basecourse materials to provide adequate resistance against damage under traffic and environmental loading is important in maximizing the life of a pavement. Cement stabilised pavements are unique materials that they exist at the border between structural soil and conventional concrete. The pavement layer are typically roller-compacted and thus require sufficient water content to achieve compaction but at the same time also requires water sufficient for cement hydration and workability with a grader. A literature review combined with simple tests are undertaken to determine fit for purpose design mix, i.e. a compaction test to ascertain the optimum moisture content (OMC) and maximum modified dry density (MMDD) and unconfined compressive strength (UCS) test. The tests showed that the MMDD for the material at various cement content are a constant, and a fit for purpose design chart can be developed based on the water and cement content. The OMC for compaction of cement treated basecourse is the OMC of the parent material + 0.25% for every 1% in cement content. This relationship between water content and cement content runs parallel to the minimum water required for effective hydration to take place, i.e. a w/c ratio of 0.25.

Keywords: cement, basecourse, pavement, mix design, unconfined compressive strength.

1. Introduction

Stabilisation is a process of prescribing additives or binding agents to soil based materials to increase the performance of the materials for a specified purpose [1]. Although with the variety of binding agents, cement is investigated in this paper due to its versatility for application as a stabilising agent for the majority types of soils [2] and its familiarity to the construction industry as shown in the excerpt from AustStab [2] and Austroads [3] in Figure 1 below. When cement is treated to soil, the stabilisation product is referred in general terms as soil-cement.



Particle size	MORE THAN 25% PASSING 0.425 mm			LESS THAN 25% PASSING 0.425 mm		
Plasticity index	PI ≤ 10	10 < PI <20	PI ≥ 20	PI ≤ 6 WPI ≤ 60	PI ≤ 10	PI > 10
Binder type						
Cement and cementitious blends*	■	▥	□	■	■	■

Key	Usually suitable	■	Doubtful or supplementary binder required	▥	Usually not suitable

Figure 1. Suitability of cement as a stabilising agent [2]

Soil-cement was first concocted in 1930s in a joint project between the South Carolina State Highway and the Portland Cement Association (PCA) [4], who have since then been the leading experts in advancing studies in cement stabilisation. Among the application of soil-cement combinations, attention has been given to the stabilisation of pavement base course materials, typically composed of granular soil, as it forms the dominant structural layer in a pavement. The stabilisation of base course with cement is industrially known as Cement Treated Base (CTB) and is widely used in the United States, the Republic of South Africa and China [5].

In Australia, cement became a mainstream stabilising agent in eastern Australian states as early as 1950 through the establishment of a specialist contractor, leading to the construction of in situ stabilisation of local government roads in 1960s [6,7]. Motivated by sustainability of sourcing fit for purpose quality aggregates that meet performance criteria, deliver potential cost savings [5,8] and meet demands of continual increase of road networks in Australia [9], the use of cement stabilisation continues to present day and is even recognised as a potentially cost effective solution for rural road construction [8].

Cemented base course are a unique material in engineering as the material's behaviour spans between behaving as a "modified" unbound material to being a stiff material comparable to concrete. PCA [10] have identified the production of diverse forms of soil-cement for different application and purposes by varying cement and water content. In comparison, Australia differentiates the varying percentage of cement content by its mechanical behaviour and degree of binding only, i.e. unbound, modified (semi-bound) and stabilised (bound).

Current Australian guidelines for stabilisation mix designs are provided by Austroads [3]. These guidelines emphasise mainly of the selection of binder type and provide approaches for assessing the structural properties of the mixture.

The strength and durability aspects of the pavement has been addressed by the author in other publications with this paper focusing on the challenges in proportioning materials to meet the design purpose of CTB in the context of Western Australia.

2. Considerations for Mix Design

Material used in Cement treated base (CTB) comprises of three elements, i.e. aggregate, cement and water. In Western Australia, the selection of aggregates is dictated by Specification 501 [11]. The aggregates used in this study are crushed rocks sourced from Holcim Quarry in Gosnells, WA and comply with these requirements. General Purpose (GP) cement has been used for this study as studies undertaken by Butkus and Lee Goh [12] and Butkus [13] shows that the use of GP cement shows better performance compared to General Blend (GB) cement.

The proportioning of the three elements is crucial in order to provide a fit for purpose design. This paper provides a literature review of the roles and requirements of each element along with simple tests to construct a material chart. These elements include:

- Water content
- Compaction
- Cement Content
- Compressive Strength

2.1 Water Content and Compaction

Unlike traditional concrete where water content is primarily driven by the workability of mixture and strength, water in the mix design of cement treated basecourse serves a third purpose of ensuring compaction of the basecourse is reached. The workability required for the mixture differs to that of traditional concrete since the material is placed via roller-compacting efforts instead of wet-forming Austroads [14].

The gain in strength of a material is primarily a function of cement, but water plays a crucial role in ensuring that the hydration of cement is supplemented with the sufficient amount of water. Without sufficient water, the cement hydration process will not be fully activated [15]. The minimum water to cement ratio to allow hydration to occur is 0.22 to 0.25 [15,16]. At water to cement ratio in excess of 0.45, the hydration process is also overly diluted and creates porous matrices that are low in strength [15].

Moreover, the increase in water content also reduces the strength properties of the material measured using the Unconfined Compressive Strength Test as shown in Figure 2 below [17]. The results were commissioned by Main Roads Western Australia to assess the response of cement treated base course to changes in density and moisture ratio at compaction. Results show trends in unconfined compressive strength after 7 days, 28 days and 12 months of curing. The results show in Figure 2 shows that an increase in moisture content at compaction reduces the strength of the material.

Being predominantly soil in compound, the strength of the material is dependent on the compaction level achieved. As expected of the material, the unconfined compressive strength of the material increases with the density of the material.

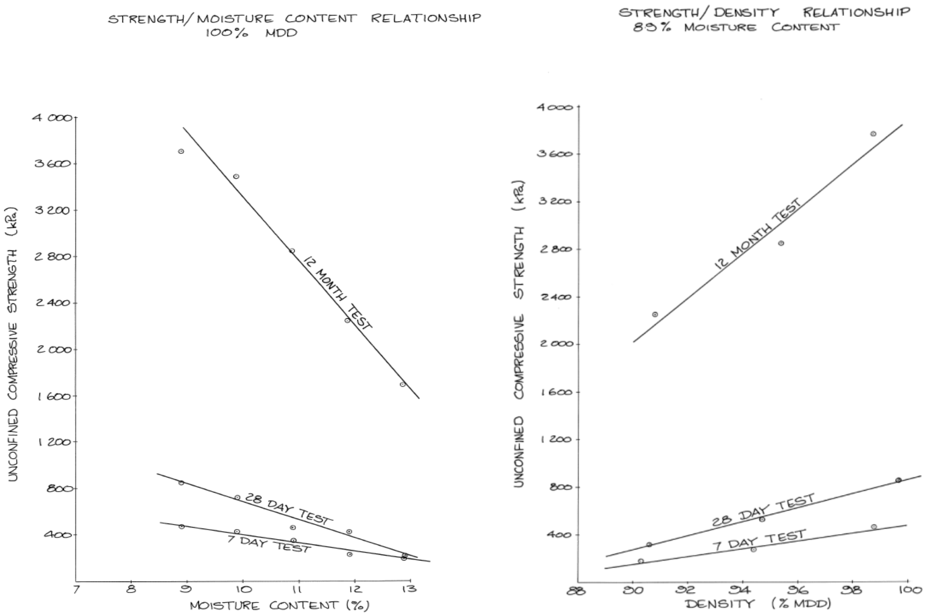


Figure 2. Relationship Between UCS vs moisture content and density [17]

With the negative impact of moisture content and the positive impact of moisture content, the optimum moisture content corresponding to the maximum dry density is ideal for the preparation of cement treated basecourse. A compaction test is therefore undertaken as part of this study to determine the maximum modified dry density of the material in accordance with Test Method WA 133.1. The results of the compaction test area as shown below:

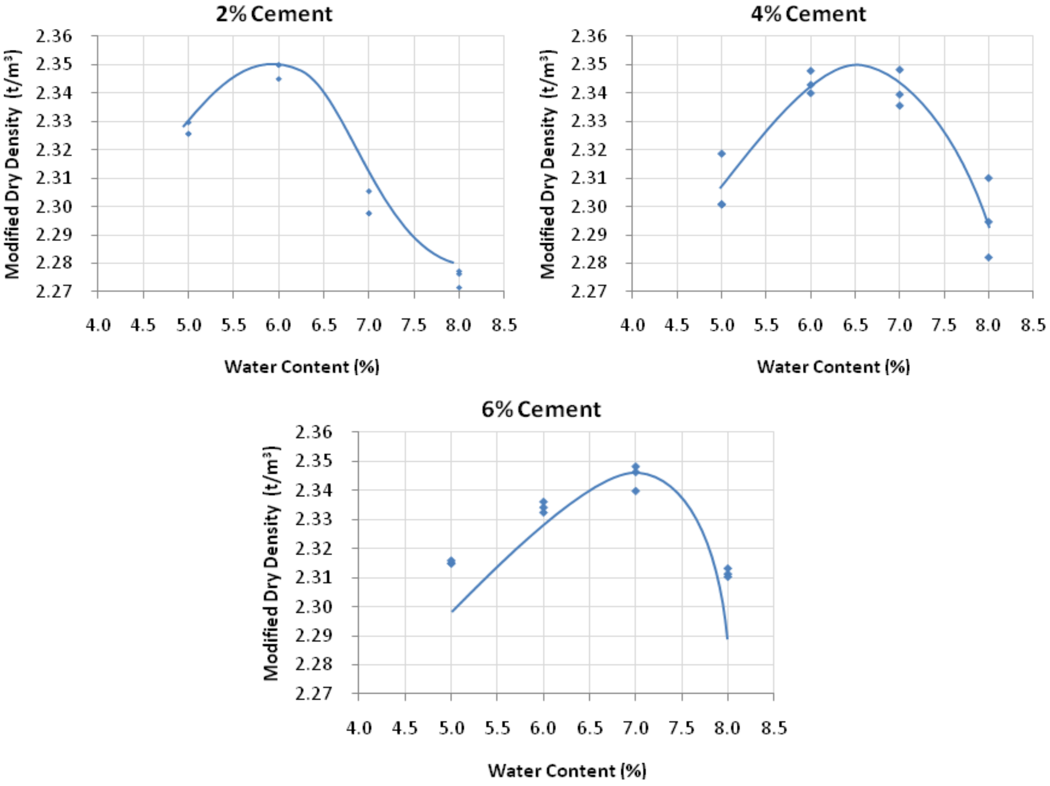


Figure 3. Compaction test results

As seen from the compaction test results, little variability in maximum modified dry density can be observed from varying cement content, where density can be estimated to remain constant at 2.35 t/m^3. However, the optimum moisture content corresponding to the tests show that the increasing cement content requires an increase in water content to achieve maximum compaction.

This can be potentially explained with the conglomeration of fines which affects the void ratio of the mix and the absorption of cement during the reaction process.

Another explanation of this is that the free water available within the voids are consumed by the hydration process of cement. By interpolating the results from the compaction tests, the increase in OMC is 0.25% for every 1% of cement as summarised in Table 1 below. This corresponds well with the minimum required water cement ratio as discussed earlier in this section.

Table 1. Relationship between cement content, OMC and W/C ratio

Cement Content	1	2	3	4	5	6
Optimum Moisture Content (MMDD = 2.35 t/m^3)	5.75	6.00	6.25	6.5	6.75	7.00
W/C Ratio	0.17	0.33	0.48	0.62	0.74	0.85

2.2 Cement Content and Performance Measure by Unconfined Compressive Strength

The cement phase within CTB forms an interlocking matrix between the aggregates and binds the aggregates together. This process causes the development of tensile strength which in turn gives added flexural stiffness to pavements, minimising permanent deformation. The minimum practical cement content that should be treated to soil is to be 1% [2] to ensure consistency of the material mix and ranges to typically 5%.

The Unconfined Compressive Strength is widely accepted as the classification criterion for cemented materials within the transportation industry because of its relative ease and speed to undertake. Although, it does not provide any input to design but have shown some relationship with various mechanical properties of CTB, the Unconfined Compressive Strength (UCS) provides an indicative measure of the normal stress and cohesive shear strength of the cement matrix, which is an expression of the degree of binding achieved from the mix design. Furthermore, the compressive strength is also used to categorise conventional concrete. Typical UCS and compressive values of these different categories are presented in Table 2 below.

Table 2. Compressive strength criteria of different classification of cemented basecourse

Classification	Testing Criteria	Source
Modified	0.7 MPa < UCS < 1.5 MPa	Austroads [8]
Lightly Bound (Stabilised)	1.5 MPa < UCS < 3 MPa	Austroads [8]
Bound (Stabilised)	UCS > 3 MPa	Austroads [8]
Lean Mix	6 MPa < f_{cm} < 15MPa	DTMR [19]
Conventional Concrete	f_{cm} > 20 MPa	Australian Standard [20]

The UCS of CTB has been measured by this Author and published in other publications. The UCS results of CTB are repeated in Table 3 below for completeness with an indication of the classification of the material based on Table 2:

Table 3. Unconfined compressive strength (UCS) of tested cement treated crushed rock

Cement Content	2	3	4	5
UCS (MPa)	4.85	6.08	6.71	7.42
Classification	Heavily Bound	Heavily Bound	Heavily Bound to Lean Mix	Lean Mix

3. Mix Design Chart

The interaction of the various parameters discussed in this paper highlights the interdependency and the conflict of the mixes, resulting in proper manipulation of the mix design an arduous task. Figure 4 below is built upon the factors discussed in this paper and presents the different categories of materials achieved from varying cement content, water content and to a lesser extent the compaction effort. The Figure is adapted from Thom [15] and PCA [10].

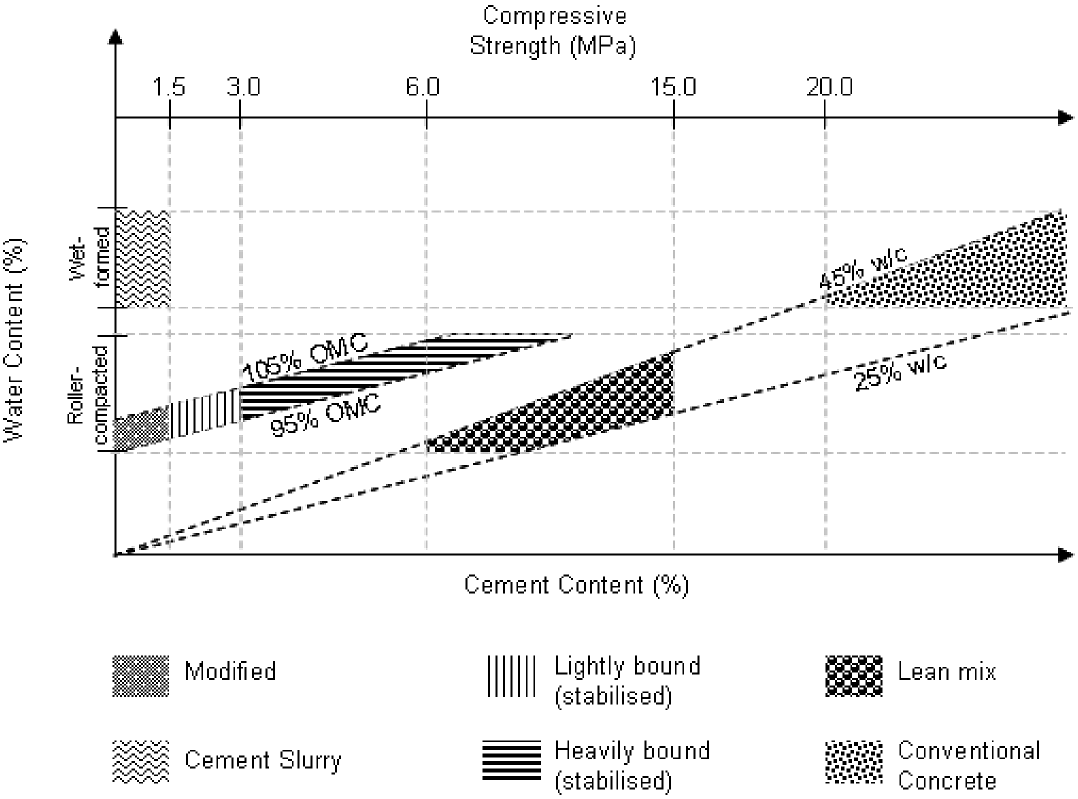


Figure 4. Mix design chart for cemented materials

The required water content to achieve compaction for the tested material means that the cement are overly saturated, porous and weak in strength, a specific trait that differs cement treated basecourse (CTB) from conventional concrete. However, since the predominant resistance of the material is gained from the shear resistance of the aggregates, the cement matrix that forms around the aggregates provides added resistance to the

4. Conclusion

Several conclusions can be drawn from the simple analysis and literature study undertaken in this paper:

1. CTB are a unique material which oversaturates the material in terms of water required for cement hydration which will increase the porosity of the cement matrix and thus reducing strength. However, pavement shear strength are dictated by density and therefore the OMC is to be used for optimum performance and workability when using CTB.
2. The OMC for compaction of CTB is the OMC of the parent material + 0.25% for every 1% in cement content. This relationship runs parallel to the minimum water required for effective hydration to take place, i.e. a w/c ratio of 0.25. It is believed that this occurs due to the absorption of water by the cement paste for hydration and the reduction in fines due to the conglomeration of fines within the cement matrix.
3. The different mixes and use of soil-cement can be shown graphically as per Figure 4.
4. The cement treated crushed rock basecourse available in Western Australia falls within the highly stabilised to lean mix region.
5. Further work should be commissioned to determine the water content limits for roller compaction and wet forming. A slump test was initially planned as part of this paper but did not provide conclusive results. It is recommended that past experiences be drawn for this purpose.

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