Characteristics and Performance of Cement Modified–Base Course Material in Western Australia

Peerapong Jitsangiam[1]; Suphat Chummuneerat[2]; Tanapon Phenrat[3]; and Hamid Nikraz[4]

Abstract: Hydrated cement–treated crushed rock base (HCTCRB) is produced by adding 2% Portland cement (by mass) to a standard crushed rock base (CRB) at an optimum moisture condition. The unique production process for HCTCRB is different from that of a common cement-treated base in that a remixing process is performed after the hydration of cement, preventing cementitious bonding to maintain the unbound material characteristics with an improvement in material engineering properties. This paper presents the resilient modulus (M_R) and permanent deformation (PD) characteristics of HCTCRB after variable hydration periods, water addition during compaction, and dryback. The difference in material hydration periods affected the performance of HCTCRB. However, in this study, a consistent performance trend with various hydration periods could not be found. Moisture contents have a major influence on the properties of HCTCRB. The results indicate that a higher moisture content increases the PD and decreases the M_R of this material. The addition of more water during compaction caused inferior PD and M_R performance even though the samples achieved a higher dry density. A dryback process to achieve a dryer condition can improve material performance. After samples were subjected to a dryback process, it was found that samples prepared by adding water during compaction showed a decrease in material performance compared with samples that were compacted without additional water. Thus, the amount of water added to mixes during compaction must be controlled. **DOI: 10.1061/(ASCE)MT.1943-5533.0000930.** *This work is made available under the terms of the Creative Commons Attribution 4.0 International license, http://creativecommons.org/licenses/by/4.0/.*

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Introduction

Cement stabilization for road pavements was first developed in Australia in the 1950s (Yeo and Nikraz 2011). However, this technique was not used in Western Australia (WA) until 1975 when Main Roads Western Australia (MRWA) examined the performance of stabilized limestone using cement in comparison with bitumen stabilization, the common stabilizer applied in WA on that time. Consequently, the results of the experimental works from this project led MRWA to undertake constructed pavement trials on the Leach Highway within the Perth metropolitan area in 1977, using 1 and 2% bitumen and 2% cement for the limestone base course. Assessment of these pavements in 1980 using accelerated loading facility tests ascertained that the cement-treated section in this pavement trial performed the best. However, based on this study, there was a concern about the risk of cracking and the lack of comprehensive fatigue failure criteria.

In 1992, MRWA introduced the development of a unique base course material used in WA, called hydrated cement–treated crushed rock base (HCTCRB), which has increased strength, reduced permanent deformation, and less moisture susceptibility while still behaving as an unbound material (Yeo and Nikraz 2011).

The general definition of HCTCRB is a manufactured road base material, made by blending standard crushed rock base (CRB) with 2% cement (general purpose Portland cement) by mass of CRB at the optimum moisture content (OMC) obtained by the MRWA Test Method WA 133.1 (MRWA 2007). It is mixed and stockpiled for a suitable hydration period. HCTCRB is not like a modified or stabilized cement-treated base, as after a suitable hydration period it is re-treated to maintain the properties of the unbound material (by breaking the cementitious bonds generated during the hydration time with remixing processes before compaction). This prevents drying shrinkage cracks, which usually occur in cement-treated materials. HCTCRB has also been trusted locally as the sufficient (relatively high) modulus material for heavy traffic pavements such as freeways. However, in the last 10 years, there was significant premature damage on some highways and roads in WA constructed with HCTCRB base course. This has led to a demand for more effective use of HCTCRB in WA pavements.

This paper presents an investigation of the mechanical behavior of HCTCRB through repeated-load triaxial (RLT) test results with related resilient modulus and permanent deformation characteristics. Practical factors during the production and construction of HCTCRB, such as hydration periods, addition of water during compaction, and the dryback process, were also investigated to understand how these factors affect the performance of HCTCRB.

Materials and Testing

The standard CRB used in this study was collected from a local quarry in Perth. The stabilizing agent, Portland cement type GP,

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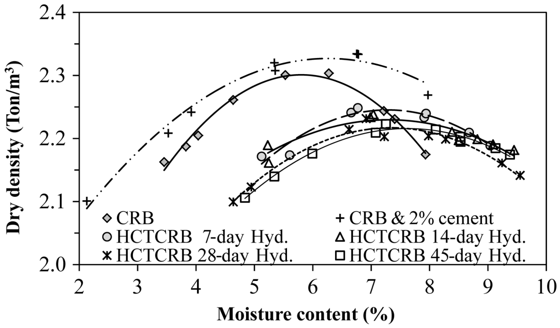

Fig. 1. Moisture–density relationships of CRB, CRB cement, and HCTCRB

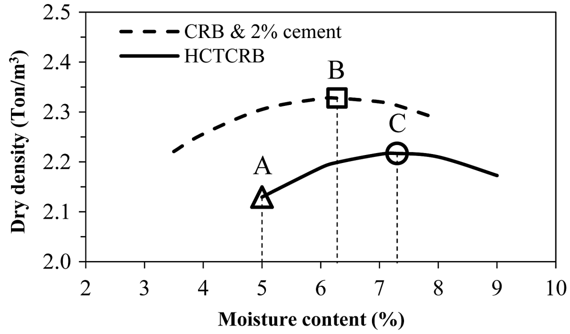

Fig. 2. Schematic compaction curves showing the moisture conditions of the study's test samples

conformed to the standard AS 3972-1997 (Australian Standard 1997). In this study, HCTCRB samples were prepared by blending crushed rock with 2% cement (by dry mass of CRB) and 6.26% water (by dry mass of CRB and cement blend), which was derived from the modified compaction test result of a CRB–cement mix following test method WA 133.1 (MRWA 2007). Moreover, this amount of water was in accordance with the specifications (MRWA 2012), which is the minimum moisture content of the mix at 90% OMC of CRB. The CRB and cement mixtures were put in sealed plastic bags and stored in a temperature-controlled room (25°C) to maintain the constant curing condition for a laboratory purpose with the 7-, 14-, 28-, and 45-day hydration periods for HCTCRB with a re-treating process. Modified compaction tests were then performed on each HCTCRB sample. The moisture–density relationships [i.e., the OMC and maximum dry density (MDD)] of the materials in this study are presented in Fig. 1.

Performance Tests for HCTCRB

The mechanical material properties of permanent deformation (PD) and resilient modulus (M_R) were investigated through RLT tests, in accordance with Austroads standard test method AG PT/T053 (Austroads 2007). The samples were prepared using a modified compaction method in a standard 100-mm-diameter and 200-mm-height mold. Compaction was achieved with 25 blows of a 4.9-kg rammer at a 450-mm drop (height) in eight layers, which provided compaction energy of 21.62 J per blow. This study investigated the effect of hydration periods, water addition during compaction, and dryback on the PD and MR of HCTCRB. *Dryback* is the process in which the material is allowed to dry out after compaction, to a certain amount of a moisture content, with the main purpose of maximizing the pavement service life, along with improving the performance of asphalt surfacing by allowing satisfactory penetration of a primer binder into the pavement surface (ARRB 2003).

In this study, the effect of the hydration period was investigated at 7, 14, 28, and 45 days. There were three different levels of water addition during compaction, namely Types A, B, and C. Fig. 2 presents a schematic diagram for moisture conditions of these three types of samples. For Type A, each mix was compacted without additional water (i.e., at the moisture condition at the end of a hydration period); therefore, the moisture contents of HCTCRB samples after the re-treating process were 5.7, 5.6, 5.3, and 5.0% for 7, 14, 28, and 45 days of hydration periods, respectively. Type B represents the amount of water added to the HCTCRB sample during compaction up to the OMC of the CRB–cement mixture (6.26%). Finally, Type C samples are the samples that were added the water to reach the OMC of the individual hydration period (i.e., 7.28, 7.30, 7.34, and 7.62% for 7, 14, 28, and 45 days of hydration periods, respectively). After compaction, the samples were dried using a dryback process before the tests. Three degrees of dryback conditions were used: no dryback, dryback to 80% of OMC, and dryback to 60% of OMC.

Experimental Results and Discussion

Effect of Hydration Periods and Amount of Water Added during Compaction on the Performance of HCTCRB

The dry density of all tested samples with respect to their individual MDD (Fig. 1) are summarized in Table 1. All samples were tested immediately at the end of the 28-day curing time without a dryback process. Generally, the dry density of the Type A and B samples were lower than that of Type C, because Type A and B samples were compacted at a moisture content lower than their OMC.

Figs. 3 and 4 present the RLT test results of HCTCRB with variation of hydration periods (7, 14, 28, and 45 days) and water addition (types A, B, and C). The effect of hydration periods on HCTCRB performance could not be determined because the related consistent trends between PD and M_R versus the hydration periods cannot be constructed in the good relationship. However, the moisture content of the test samples shows a significant effect on the RLT results, regardless of the dry density. The higher water addition up to the optimum moisture content of HCTCRB (i.e., Type C samples) resulted in a decrease in M_R and an increase in PD of the material, even though it induced a higher dry density, which indicates that HCTCRB is still susceptible to a range of moisture contents.

Effect of Moisture Contents after Dryback Processes on the Performance of HCTCRB

The samples with 28- and 45-day hydration periods and three levels of water addition (A, B, and C) were tested after a dryback process at three different levels (i.e., no dryback, dryback to 80% of OMC, and dryback to 60% of OMC). Based on the dryback process in this

Table 1. Dry Density of HCTCRB Samples with Respect to Their Individual MDD

Hydration period	Type A	Type B	Type C
7 days	93.7% MDD	95.8% MDD	98.4% MDD
14 days	94.1% MDD	99.6% MDD	98.3% MDD
28 days	93.4% MDD	97.6% MDD	98.7% MDD
45 days	93.2% MDD	95.2% MDD	99.3% MDD

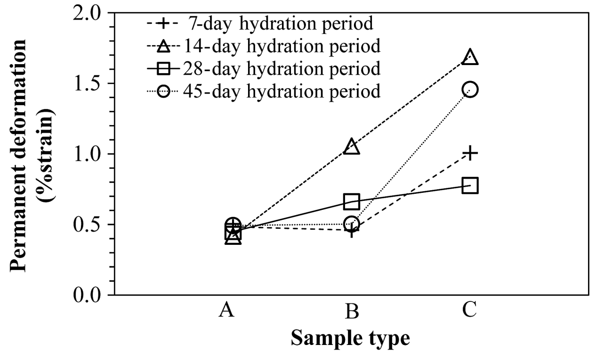

Fig. 3. PD of HCTCRB with variation in hydration period and water addition (no dryback)

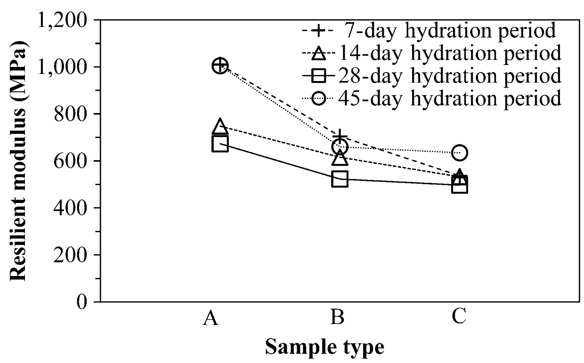

Fig. 4. MR of HCTCRB with variation in hydration period and water addition (no dryback)

study, the moisture content of the HCTCRB with 28- and 45-day hydration periods decreased to approximately 80% of the OMC of the CRB-cement mixture as a consequence of water consumption through the hydration reaction and curing processes. Table 2 shows the moisture content after curing and dry density of the samples used in this study.

The series of PD and M_R results are presented in Figs. 5 and 6, respectively. Both figures clearly show that adding water during compaction and dryback (which are generally performed in the field) significantly affects the performance of HCTCRB in terms of PD and M_R. In general, a higher amount of water added during compaction causes a decrease in PD and M_R performance (compared with samples without the addition of water). Even though the samples have higher dry densities, they do not show better performance after curing. This indicates that without dryback, HCTCRB tends to show moisture sensitivity. The dryback process, which is aimed to achieve a dryer condition to maximize the pavement life, can also show improvement in HCTCRB performance, although it depends on the amount of additional water. After a

Table 2. Moisture Content and Dry Density of HCTCRB Samples

	Moisture content[a]		
Sample	% OMC_m	% OMC of HCTCRB	Dry density[b]
28A	80.5	68.9% OMC_{28}	93.4% MDD_{28}
28B	97.9	83.8% OMC_{28}	97.6% MDD_{28}
28C	113.6	97.2% OMC_{28}	98.7% MDD_{28}
45A	77.3	63.7% OMC_{45}	93.2% MDD_{45}
45B	98.0	80.8% OMC_{45}	95.2% MDD_{45}
45C	117.8	97.1% OMC_{45}	99.3% MDD_{45}

[a] OMC_m, OMC_{28}, and OMC_{45} denote the OMC of CRB-cement mix, HCTCRB of 28 days, and HCTCRB of 45 days of hydration period, respectively.
[b] MDD_{28} and MDD_{45} denote the MDD of HCTCRB at 28- and 45-day hydration periods.

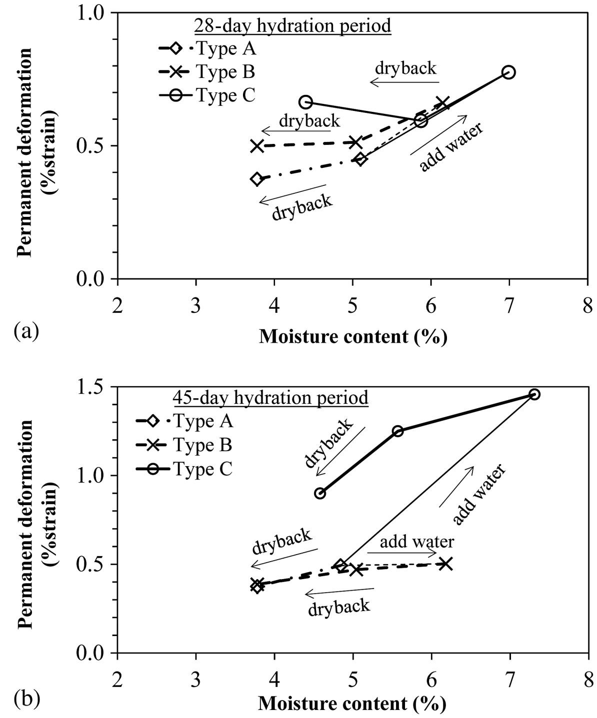

Fig. 5. PD of HCTCRB samples with variation in water addition and the degree of dryback for (a) 28-day hydration period; (b) 45-day hydration period

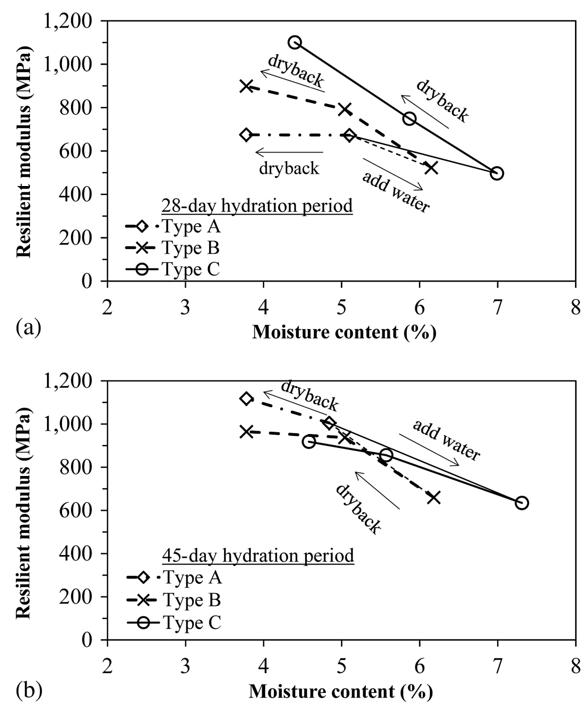

Fig. 6. Resilient modulus of HCTCRB samples with variation in water addition and degree of dryback for (a) 28-day hydration period; (b) 45-day hydration period

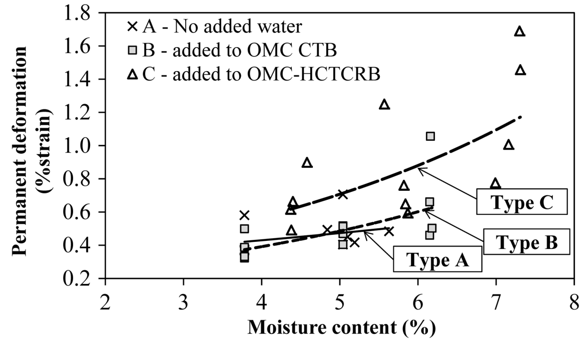

Fig. 7. PD of HCTCRB samples with 7-, 14-, 28-, and 45-day hydration periods with variation in moisture content

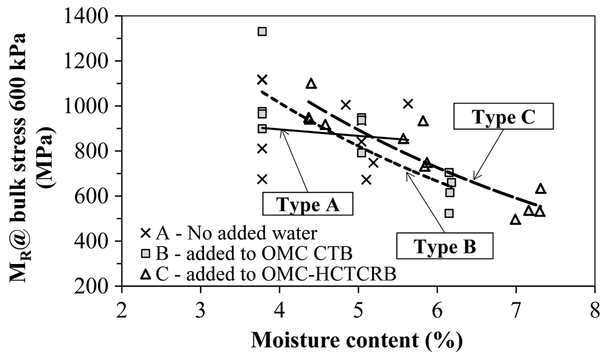

Fig. 8. MR of HCTCRB samples with 7-, 14-, 28-, and 45-day hydration periods with variation in moisture content

dryback process was performed on all test samples, an evaluation of the material performance was made in comparison with the no-dryback samples at the same water content. The M_R of the Type B and C samples were found to be almost equivalent to those of Type A, whereas the PD values of the Type B and C samples were higher than or equivalent to those of Type A. Based on the results of this study, HCTCRB still does have some degree of moisture sensitivity, which needs to be addressed concerning the effective use of this material.

Implications of the Experimental Results

The PD and M_R test results for all HCTCRB samples (7-, 14-, 28-, and 45-day hydration periods) under variations of moisture content during compaction and dryback are presented in Figs. 7 and 8. A higher amount of water added during compaction (Types B and C) to the test samples tends to deteriorate PD and M_R performance (compared with samples without additional water), even though all of these samples have higher dry density conditions. Although samples of Types B and C were dried to the same level as the Type A samples, PD values decreased but were still higher or equivalent to that of Type A. The M_R of the Type B and C samples could be improved to be comparable with that of Type A at the same moisture content. Hence the dryback process shows potential to improve material performance, depending on the amount of water added. Higher water additions, even to the OMC of HCTCRB, resulted in more defective performance, although it can induce a higher dry density. This effect indicates that HCTCRB is still susceptible to a range of moisture contents. Based on these findings, in practice, adding water to the material in the field to increase the workability of the material in compaction would cause significant concern as it may result in adverse performance of the HCTCRB.

Summary and Conclusions

This study aimed to examine the M_R and PD of HCTCRB conducted under various conditions of water addition during compaction and dryback. In this study, three different levels of water addition (i.e., Types A, B, and C)—representing no additional water, added water to the OMC of the CRB-cement mixture (6.26%), and added water to the OMC corresponding to the individual hydration period, respectively—were designed to investigate the effect of this water on the overall performance of the samples. Finally, the samples were subjected to a dryback process before the performance tests. Three degrees of dryback were examined (i.e., no dryback, dryback to 80% of OMC, and dryback to 60% of OMC). The major conclusions obtained from the material characterizations are as follows:

1. Differences in the hydration period affect the performance of HCTCRB. However, a consistent performance trend with a hydration period could not be found;
2. The higher moisture-content samples tend to show an increase in PD and a decrease in MR of this material. Adding more water during compaction to the test samples can cause the deterioration in their PD and MR performance, even though all of the test samples have higher dry density conditions; and
3. Using a dryback process to achieve a dryer condition can improve material performance. After the test samples were subjected to a dryback process, the test samples prepared by adding water during compaction showed a comparable M_R; however, they showed a decreased performance in terms of PD in comparison with the test samples compacted without additional water. Thus, the amount of water added to the mixes during compaction must be carefully controlled.

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References

Australian Road Research Board (ARRB). (2003). *APRG technical note 13: Control of moisture in pavements during construction*, Melbourne, Australia.

Australian Standard. (1997). *AS 3972-1997 Portland and blended cements*, Standards Australia, Sydney.

Austroads. (2007). *AG PT/T053: Determination of permanent deformation and resilient modulus characteristics of unbound granular materials under drained conditions*, Austroads, Sydney, NSW, Australia.

Main Roads Western Australia (MRWA). (2007). *Test method WA 133.1 dry density/moisture content relationship: Modified compaction fine and medium grained soils*, Perth, WA.

Main Roads Western Australia (MRWA). (2012). *Specification 501 pavements*, Perth, WA.

Yeo, Y. S., and Nikraz, H. (2011). "Cement stabilisation of road base course: A chronological development in Western Australia." *Aust. Geomech.*, 46(3), 53–62.