MECHANICAL BEHAVIOURS OF A BASE COURSE MATERIAL IN WESTERN AUSTRALIA

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ABSTRACT

Hydrated Cement Treated Crushed Rock Base (HCTCRB) is produced by adding 2% Portland cement (by mass) to a standard crushed rock base. The mix is disturbed after hydration to prevent setting up and avoid producing the base course as a bound material. This study examined the resilient modulus (M_R) and permanent deformation (PD) of HCTCRB conducted under various conditions of water addition during compaction and dryback. The results indicated that the higher moisture content of HCTCRB, the poorer performances such as permanent deformation and resilient modulus. Higher addition of water during compaction led to the inferior PD and M_R performances even though the samples achieved the higher dry density. The dryback process which reduces the moisture content can improve these performances of all tested specimens. After the tested specimens were subjected to dryback process, theirs performances were evaluated and compared at the same levels of moisture content. It was found that the tested samples that were prepared by adding the water during compaction provided the poorer or comparable performances to that of the samples that were compacted without water addition. Thus, the amounts of added water during compaction must be aware.

INTRODUCTION

Cement modification technique is employed in Western Australia (WA) for typical use as a base course material called Hydrated Cement Treated Crushed Rock Base (HCTCRB). HCTCRB is produced by stabilising a standard crushed rock base (CRB) with General Purpose-Portland cement (2% by mass of CRB). This mixture is cured for the specified hydration period according to the specification of Main Roads Western Australia (MRWA). Then, it is disturbed to prevent setting up and avoid producing the base course material as a bound material.. HCTCRB is expected to provide higher strength and lower moisture sensitivity than that of CRB, while avoiding the bound characteristics and fatigue cracking problems in cement treated material (Butkus 2004).

Over the years HCTCRB has been widely constructed as a base course material in WA, with a higher modulus value for use in heavy traffic pavements. For example, it has been successfully used for freeways. As a result of damage on some highways and roads in WA, identifications to the causes of this damage have been attempted. HCTCRB needs to be examined to discover whether factors involved in its manufacture, road design, or construction are partly responsible for the problem. Experience in its use has been gained over time. It has been found that many factors during manufacture and construction works can lead to uncertainty when using the material. Since pavement analysis and design in WA relies predominantly on empirical design, experience and basic experimentation, explanations for the damage occurring under present conditions are difficult to determine and assess. Accordingly, an understanding of the material characteristics, in accordance with the pavement mechanistic approach, is strongly advised to maximise its use. The study is a part of the project supported by the Australian Research Council (ARC) under the Linkage Scheme. This project is also designed to further standardise HCTCRB's manufacture and construction, and overcome doubts regarding its use.

This paper aims to present the mechanical behaviours of HCTCRB resulting from the repeated load triaxial testing in terms of resilient modulus and permanent deformation. The effects of construction practices such as water addition during compaction and dryback on the properties

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of HCTCRB were evaluated. These test results of HCTCRB, which are the key factors for realistic material response models, were investigated and further developed.

MATERIALS AND BASIC PROPERTIES

Standard crushed rock base (CRB) used in this study was collected from local quarry in Perth. The stabilising agent, Portland cement type GP, conformed to the standard AS 3972-1997. In this study, HCTCRB samples were prepared by blending crushed rock with 2 %-cement and 6.26%-water. This mix based on the modified compaction test result of CRB and cement followed the test method WA 133.1 (Main Roads Western Australia 2007). CRB and cement mixture were stored in sealed plastic bags for 7, 14, 28 and 45 days of hydration periods. Once completed the hydration process, each mix was then put in the mixer to break the cementitious bonds. This procedure is called the re-treating or rework process which aims to produce the cement stabilised material as an unbound base. Then, the modified compaction tests were performed for each HCTCRB sample. The moisture-density relationships i.e., the optimum moisture content (OMC) and maximum dry density (MDD), of the materials are presented in Figure 1.

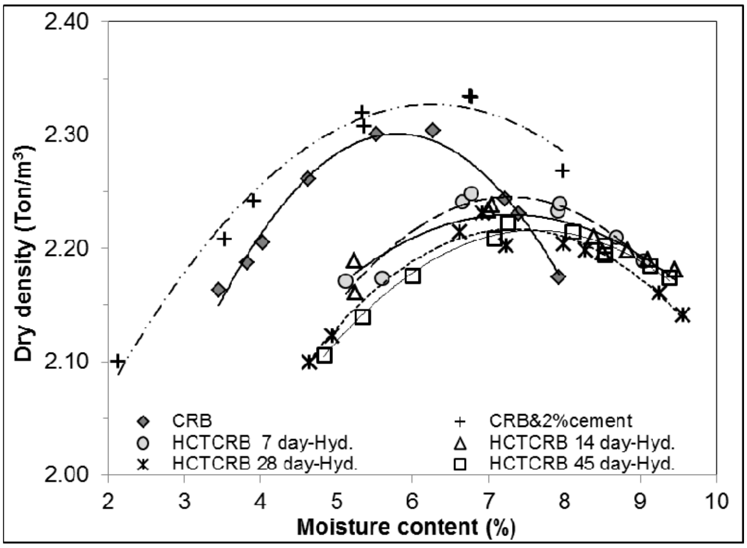

Figure 1: Moisture - density relationships of CRB, CRB-cement and HCTCRB.

The particle size distribution (PSD) of CRB and HCTCRB at various hydration periods are illustrated in Figure 2. The particle size distributions of CRB conformed to the specification limit (Main Roads Western Australia 2008). The dust ratio (the ratio of the percentage passing by mass of the 0.075mm sieve to the 0.425mm sieve) of CRB was 0.45 which was in the range 0.35 to 0.60. The PSD of HCTCRB samples were also examined even though the MRWA specification does not apply for HCTCRB. The results showed that the gradation of HCTCRB for all hydration periods did not comply with the specification. It was also found that hydration periods insignificantly differentiate the HCTCRB gradation characteristics. The dust ratio of HCTCRB samples ranged from 0.05 to 0.23. The uniformity coefficient (C_u) and coefficient of curvature (C_c) of CRB were 12.5 and 2.0 respectively. C_u values ranged from 6.1 - 7.4 and C_c values varied from 0.8 – 1.2 for HCTCRB samples. The gradation curves of HCTCRB shift to the right of the CRB curve due to a cementitious reaction with fine particles of CRB forming the larger grains, while the coarse grains were unable to maintain cement bonding after the rework process.

The material's properties from compaction and gradation tests are summarised in Table 1. Compare to CRB, the OMC of HCTCRB considerably increased about 25 percent, while the corresponding MDD marginally decreased 3 percent. There were slight increases in OMC but minor decreases in MDD for longer hydration periods of HCTCRB samples. The poorer gradation of HCTCRB induced the higher OMC and reduction in MDD due to the lack of fine

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grains and additional amounts of water were needed to lubricate the material particles during compaction.

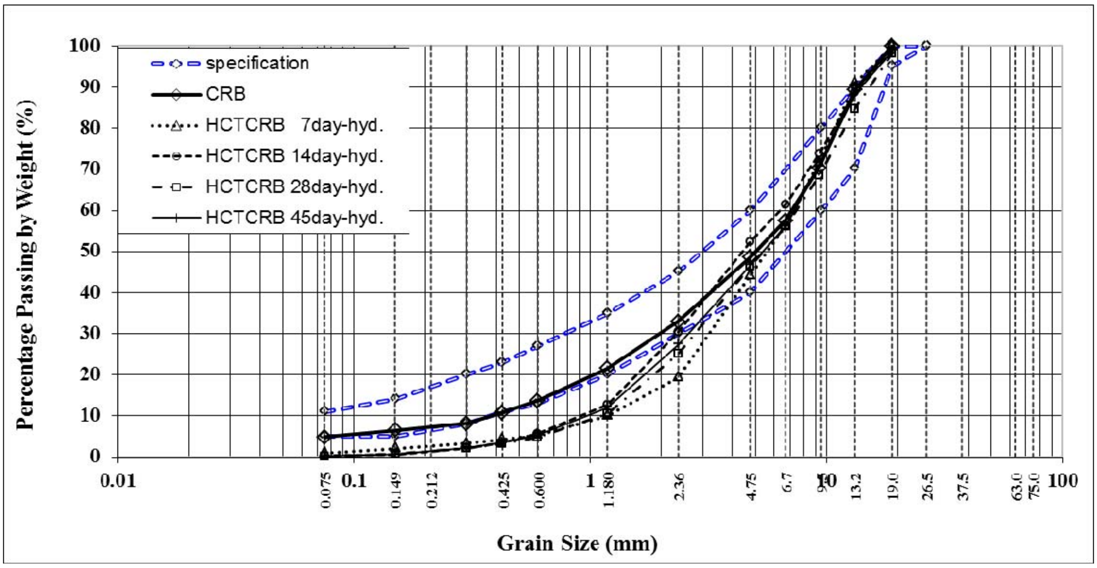

Figure 2: Particle size distribution of CRB and HCTCRB.

Table 1: The basic properties of CRB and HCTCRB.

Material	Modified compaction		Particle size distribution		
	OMC (%)	MDD (ton/m3)	Dust ratio	Coefficient of uniformity (C_u)	Coefficient of curvature (C_u)
CRB	5.80	2.301	0.45	12.5	2.0
HCTCRB					
7 day-Hyd.	7.28	2.245	0.23	6.1	1.2
14 day-Hyd.	7.30	2.230	0.08	7.0	0.9
28 day-Hyd.	7.34	2.217	0.06	6.2	0.8
45 day-Hyd.	7.62	2.216	0.05	7.4	0.9

REPEATED LOAD TRIAXIAL (RLT) TEST

Testing protocol

The mechanical properties of materials such as permanent deformation (PD) and resilient modulus (M_R) were investigated by repeated load triaxial (RLT) tests, following the Austroads standard test method AG: PT/T053 (Austroads 2007). The tests were done under drained condition and suctions were not measured. The dynamic vertical force has a period of 3 s with a load pulse width of 1 second and rise and fall times of up to 0.3 second. Permanent deformation tests were performed at constant confining pressures (σ_3) of 50 kPa throughout the testing periods. Each tested specimen was subjected to three stages of deviator stresses (σ_d), 350, 450 and 550 kPa. At each stress stage, the machine applied ten thousand repetitions of a vertical force to a specimen.

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The resilient modulus tests involve 66 stress stages of different deviator and confining stresses to simulate the sophisticated traffic loadings. The stress ratio between deviator stress and confining stress (σ_d / σ_3) varied from 2 at the first stage to 25 at the final stage. The deviator stresses varied from 100 – 600 kPa, while the confining stresses ranged from 20 – 150 kPa. Each specimen was subjected to minimum one thousand cycles of preconditioning and minimum fifty cycle-loadings at each stress stage.

Specimen preparation

Each tested specimen was compacted in mould size of 200 mm-height and 100 mm-diameter. Material for each specimen was divided and compacted evenly in eight layers. Each layer was subjected to 25 blows of a 4.9 kg-hammer and 450 mm drop height complied with the modified compaction method. The top of each layer was scarified about 6 mm-depth prior addition of material for next layer. HCTCRB samples were compacted immediately after completion of retreated processes. Then, all HCTCRB specimens were wrapped and cured in the mould for 28 days at 25° C prior to the tests.

This study investigated the effect of water addition during compaction and dryback on the permanent deformation (PD) and resilient modulus (M_R) of HCTCRB. For longer hydration period, the moisture content of CRB-cement mixes will be lower and the samples may be too dry to compact. Thus, additional water may be required for compaction. Consequently, the influence of water addition during compaction on the material performances is also examined. There were three different levels of the water addition, type A, B and C which represent no additional water, added water to OMC of CRB-cement mixture (6.26%) and added water to OMC of individual hydration period. After 28 days of curing, the specimens had been dried during dryback process prior to the tests. Three degrees of dryback were used i.e. no dryback, dryback the sample to 80% of OMC and dryback the sample to 60% of OMC.

EXPERIMENTAL RESULTS

The samples of 28 days and 45 days of hydration period with three types of water addition (A, B and C) were tested at three different levels of dryback i.e. no dryback, dryback to 80% of OMC and dryback to 60% of OMC. The moisture content of the HCTCRB at 28 and 45 days of hydration period dropped to about 80%OMC as a consequence of water consumption through hydration reaction and curing process. Therefore, sample 28A that was dried to 80% OMC and sample 28A that was not subjected to dryback was the same specimen as well as the samples of 45 days. The average moisture content after curing were 97.9% OMC for type 28B and 97.2% OMC for type 28C samples. The average dry density with respect to MDD of sample type 28A, 28B and 28C were 93.4%, 97.6% and 98.7% respectively. The average moisture content after curing were 98.0% and 97.1% of OMC for type 45B and 45C samples. The average dry density with respect to MDD of sample type 45A, 45B and 45C were 93.2%, 95.2% and 99.3% respectively.

The series of PD and MR results are presented in Figures 3 and 4, respectively. Symbol in these Figures such as 28B-80DB represents the specimen of 28 day-hydration period which was prepared by water addition type B and dried to 80% of its OMC.

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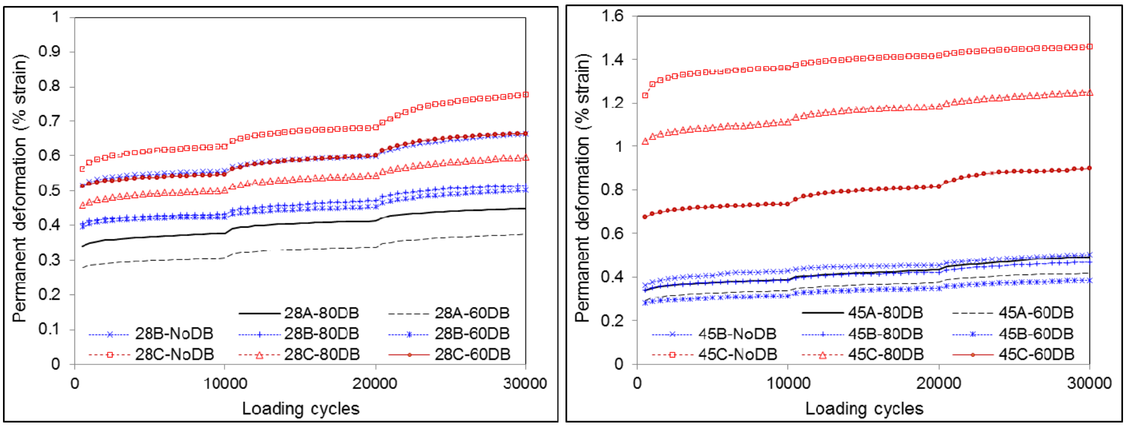
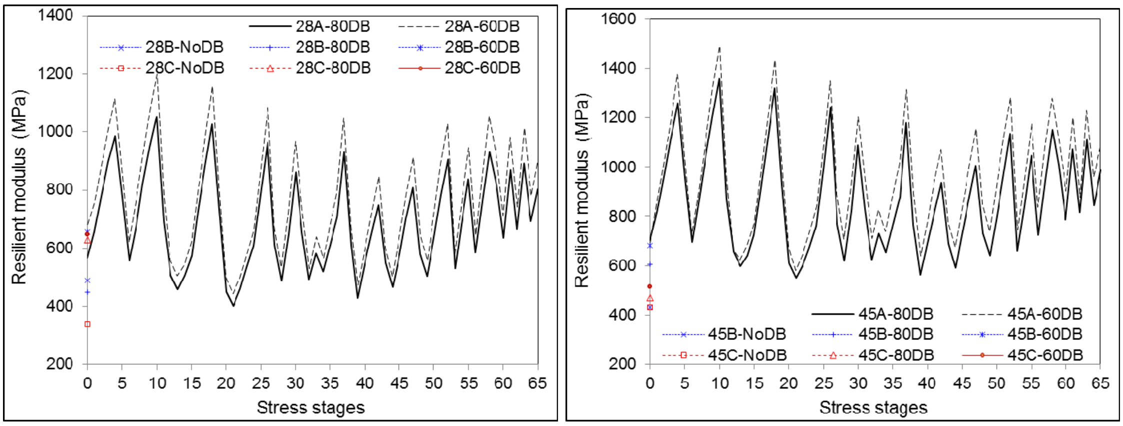
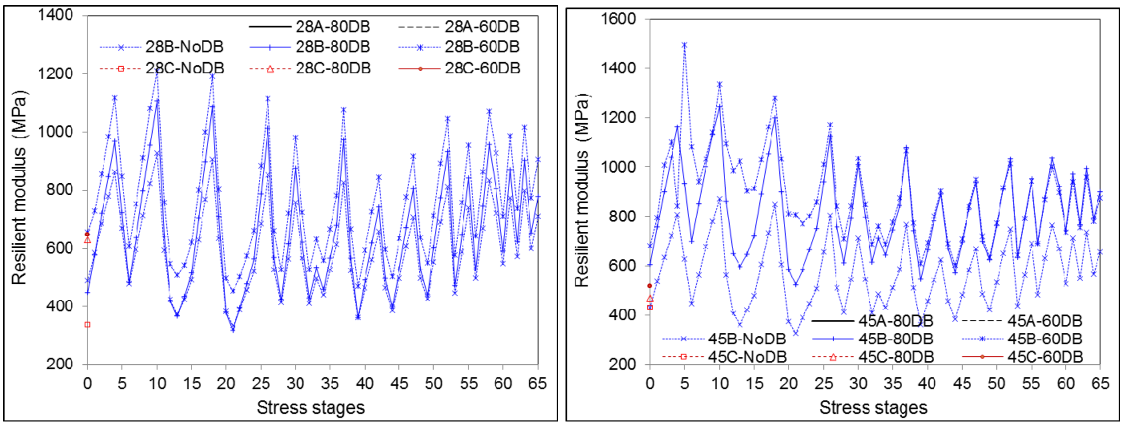


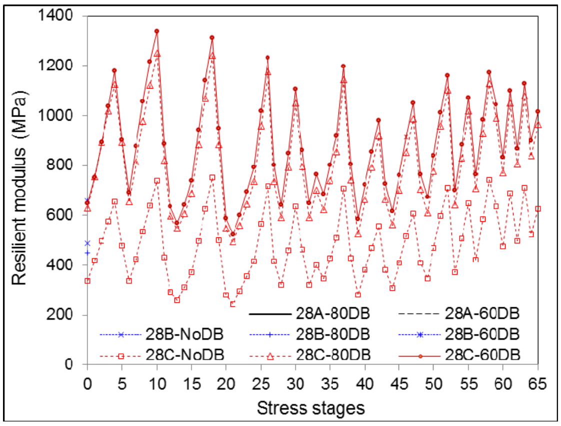
Figure 3: Permanent deformation tested results of HCTCRB samples of 28 and 45 day-hydration periods, with variation of water addition and degree of dryback.

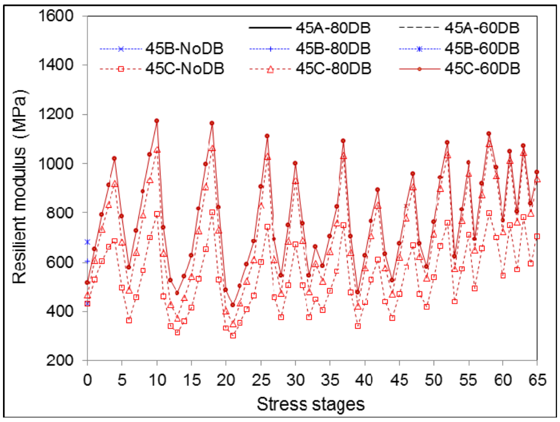


(a) M_R for samples type 28A and 45A



(b) M_R for samples type 28B and 45B





(c) M_R for samples type 28C and 45C

Figure 4: Resilient modulus tested results (followed Austroads AG: PT/T053) of HCTCRB samples of 28 and 45 day-hydration periods, with variation of water addition and degree of dryback.

Permanent deformation

PD of samples type 28A reduced from 0.45 to 0.38 %strain as the moisture content decreased from 80% to 60% of its OMC. For type 28B, the results showed the small different between PD of samples dried to 80% and 60% OMC. The % strain were 0.66, 0.51 and 0.50 for the samples of no dryback, 80%OMC and 60%OMC respectively. PD of specimen type C decreased from 0.78 to 0.60 of % strain while its moisture content dropped from 97.2% to 80% of OMC. However, the driest sample (60% OMC) deformed inauspiciously to 0.66 % strain which was greater than that of the 80% OMC.

PD of samples type 45A reduced from 0.49 to 0.42 %strain as the moisture content decreased from 80% to 60% of its OMC. For type 45B, the %strain were 0.50, 0.47 and 0.39 for the samples of no dryback, 80%OMC and 60%OMC respectively. Finally, PD of specimen type 45C were 1.46, 1.25 and 0.90 %strain for the samples of no dryback, 80%OMC and 60%OMC respectively.

Resilient modulus

Two samples of 28A provided the similar M_R, varied from 300 to 900 Mpa. For sample 28B, M_R increased from the range of 200-700 Mpa to 350-1000 MPa and 400-1200 Mpa as a result of moisture declined from 97.9% to 80% and 60% of OMC. The M_R values of sample 28C were 200-650 for no dryback sample, 380-900 for the sample dryback to 80%OMC and 800-1300 MPa for sample dryback to 60%OMC.

The M_R values of sample 45A were 550-1360 and MPa for no dryback sample and the sample dryback to 60%OMC. For sample 45B, M_R increased from the range of 330-870 Mpa to 520-1240 MPa and 600-1500 Mpa as a result of moisture dropped from 98.0% to 80% and 60% of OMC. The M_R values of sample 45C were 200-650 for no dryback sample, 350-1080 for the sample dryback to 80%OMC and 430-1170 MPa for sample dryback to 60%OMC.

Implication of the experimental results

Higher addition of water during compaction (type B and C) leads to the inferior PD and M_R performance (compared to the sample without additional water) even though the samples achieved the higher dry density. Although the samples of type B and C were dried to the same level with sample type A, PD values could be reduced but still higher or equivalent to that of type A. While, the M_R of type B and C could be improved and be comparable to that of type A at the same moisture content. The dryback process has potential to improve the material performances in different level which depends on amount of additional water. The higher water addition, even at the OMC of HCTCRB, resulted in the poorer performances although it induced the higher dry density. This effect indicated that the HCTCRB is still susceptibility to moisture content. Thus, the amounts of added water during compaction must be aware.

CONCLUSION

This study has examined the resilient modulus (M_R) and permanent deformation (PD) of HCTCRB conducted under various conditions of water addition during compaction and dryback. There were three different levels of the water addition, type A, B and C which stand for no additional water, added water to OMC of CRB-cement mixture (6.26%) and added water to OMC of individual hydration period. Finally, the specimens involved dryback process prior to the 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 characterisation are as follows.

The results indicated that the water addition during compaction and dryback significant affect the performances of HCTCRB. In general, the higher moisture content of HCTCRB, the poorer performances such as permanent deformation and resilient modulus. Higher addition of water during compaction led to the inferior PD and M_R performance (compared to the sample without additional water) even though the samples achieved the higher dry density. The dryback process which reduces the moisture content can improve these performances in different level which depends on amount of additional water. After all tested samples were subjected to dryback process, theirs performances were evaluated and compared at the same levels of moisture content. It was found that the M_R of type B and C were comparable to that of type A, while the PD performances of type B and C were still higher or equivalent to that of type A. This incidence indicated that the HCTCRB is still susceptibility to moisture content.

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