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CLAY-CEMENT ADDITIVE FOR CRUSHED ROCK BASE STABILISATION: STRENGTH PROPERTY INVESTIGATION

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ABSTRACT: With the current base course material in Western Australia, namely hydrated cement treated crushed rock base (HCTCRB), roads using HCTCRB require excessive maintenance causing from its uncertainties. This study aims to determine specific strength properties of a potential replacement material of a clay-cement stabilized crushed rock. The findings showed that a crushed rock material with a newly developed 3% clay-cement binder, possessed unconfined compressive strengths and resilient moduli significantly greater than that of HCTCRB. The developed stress dependent equation also purports that this material admixture is still exhibiting unbound performance characteristics. A material's ability to acquire the accompanying strength advantages of a 3% clay-cement binder, whilst still potentially resisting common failure methods such as shrinkage cracking, suggests that based on its potential performance as a base course layer in a pavement structure, clay-cement stabilized crushed rock base is considerable to be a viable base course material for Western Australia.

Keywords: Base course materials, Clay-cement stabilization, Crushed rock base, Pavements, Base course layers

1. INTRODUCTION

Flexible highway pavements in Western Australia are constructed in a layered idealistic design, with the pavement layers preferably constructed with locally sourced materials due to the associated economic benefits. When local materials do not possess sufficient strength for this purpose however, an alternative solution is to implement artificial (e.g., cement and lime) stabilization practices, providing a solution that is more economically viable, and one which allows the engineering properties of the material to be controlled [1]. Whilst this is a common practice adopted globally in pavement engineering practices, Main Roads Western Australia has been fundamentally unsuccessful when trying to implement this procedure for Western Australian pavements. The most recent artificially stabilized base course material implemented, hydrated cement treated crushed rock base (HCTCRB), has some uncertainties (i.e., drying shrinkage cracking, proper curing process and manufacturing issues), leading to roads using HCTCRB required excessive maintenance and rehabilitation. This has required a larger amount of capital expenditure than that expected. Therefore the investigation into a better base course material for Western Australian pavement structures is required. This paper therefore presents specific strength parameters developed in the laboratory investigation of a crushed rock base material stabilized with a newly developed clay-cement binder.

2. HISTORY OF BASE COURSE STABILISATION IN WESTERN AUSTRALIA

From the first attempted stabilization of Western Australian base course's in the 1970's, ambiguities in the resulting pavement performances have led to Main Roads Western Australia essentially prohibiting the use of stabilized pavements, and placing a number of limitations on the use of modified pavements [2].

In 1975, extensive research was commissioned into the development of a new cement binder to replace the inefficient bitumen stabilization practices that were being implemented. Initial laboratory investigations produced promising results, with limestone stabilized with 2% cement possessing strength greater than that of limestone stabilized with 3% bitumen. When sections of Leach Highway were utilized as trial pavements however, it was established that fatigue cracking was a major issue for the material due to the stiffness of the cement [3].

As a result, Main Roads Western Australia reverted back to use local materials in their virgin state, predominantly crushed rock base. After the failure of segments of the Kwinana Freeway in 1992 however, attributed to the moisture sensitivity of the crushed rock base, Main Roads once again commissioned extensive research into the development of a new base course material. After detailed laboratory testing, HCTCRB was developed, and introduced in a trial section of Reid

Highway in 1997. In 2003, field testing carried out indicated that the material exhibited strong pavement performance characteristics. In 2009 however, similar testing showed that the material was exhibiting characteristics of an unbound material, due to a retardation of the cement content over time [4]. This not only reduced the strength, but also meant the crushed rock base course was far more permeable and susceptible to moisture ingress, which was the original problem faced in 1992.

Whilst periodic changes have since been made to the material specification of HCTCRB, it is speculated that the material itself may be erratic with regard to fundamental elements such as quality control, and material uniformity [5]. With no solution developed to mitigate the sporadic performance of Western Australian pavements, the investigation into a new material was carried out, with the laboratory testing regime presented in the subsequent section.

3. LABORATORY TESTING METHODOLOGY

With the fundamental parameter of a base course being strength [6], an investigation into specific strength properties of a clay-cement stabilized crushed rock base has been undertaken. Whilst the major faults with HCTCRB were stabilizer permanency and the subsequent moisture susceptibility, if the clay-cement stabilized crushed rock did not possess sufficient strength, then an improvement in these faults would be an insignificant development. Therefore the unconfined compressive strength and resilient modulus of the material were determined, with these two parameters principle factors in determining the strength and performance of a cement treated pavement material [7]. To determine these material properties, two standardized tests were undertaken, namely an unconfined compressive strength test in accordance with [8], and a repeated load triaxial test in accordance with [9]. Fig.1 demonstrates the repeated load triaxial test apparatus used in this study.

These tests were carried out on specimens of a naturally occurring crushed rock material, stabilized with a composite artificial binder. This consisted of a synthetic kaolin clay, and general purpose cement, ranging in contents of 1%, 2%, and 3% by dry mass respectively.

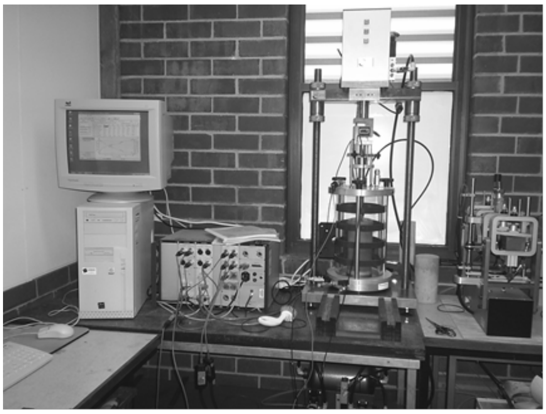

Fig.1 Triaxial test machine used in this study.

4. EXPERIMENTAL RESULTS & ANALYSIS

The initial stages of testing developed the optimal binder ratio of clay to cement required for the desired performance as a base course material. Subsequent testing was then carried out to obtain the data previously detailed in the laboratory regime, namely the unconfined compressive strength, compressive modulus, resilient modulus, and the stress dependent parameters of the clay-cement stabilized crushed rock base.

4.1 Selection of Optimal Binder Ratio

A clay-cement stabilized crushed rock base material has never been previously developed, so the ratio of clay to cement that will optimize the performance of the crushed rock base was initially determined. This involved compaction testing and unconfined compressive strength testing on the fines of a crushed rock base material, stabilized with 2% kaolin clay, 1% kaolin clay and 1% cement, and 2% cement respectively. The fines of the crushed rock base material were utilized due to soil-cement matrices developing easier around smaller sized particles [10], therefore the effect that each binder would be magnified.

The unconfined compressive strength of each material admixture is presented in Fig.2. As this figure details, there is a direct increase in the strength of the material with an increase in cement content. Whilst the 2% cement specimens exhibited additional strength, the 1% clay – 1% cement samples still possessed the strength greater than that of HCTCRB at the same age, of approximately 0.75 MPa. This was also sufficient for the material to be classed as a modified pavement material.

Compaction testing also detailed that the 1% clay – 1% cement samples possessed a larger maximum dry density than the 2% cement samples, with past research detailing that soil materials with a larger dry density will have an increase in strength occurring over a longer period of time [11]. With past field investigations by Main Roads also concluded that 2% cement samples are subject to fatigue failures [3]. It was established that a binder of one part kaolin clay to one part cement was optimal. Therefore, for the next stage of testing, all specimens were prepared with a clay-cement binder at a 1:1 ratio.

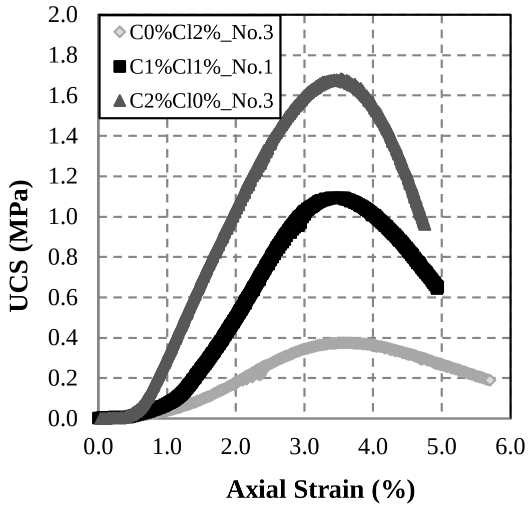

Fig.2 Unconfined compressive strength of varying artificial binders.

4.2 Unconfined Compressive Strength of Clay-Cement Stabilized Crushed Rock Base

The unconfined compressive strength for crushed rock base specimens stabilized with 1%, 2%, and 3% clay-cement binder contents, at 7 and 28 days respectively, is presented in Fig.3. As this figure details, there is a strong linear correlation between an increase in binder content and an increase in the material's unconfined compressive strength for both curing time durations. There is also a distinct increase in strength over time, with the 2% and 3% specimens tested at 28 days significantly stronger than those tested at 7 days.

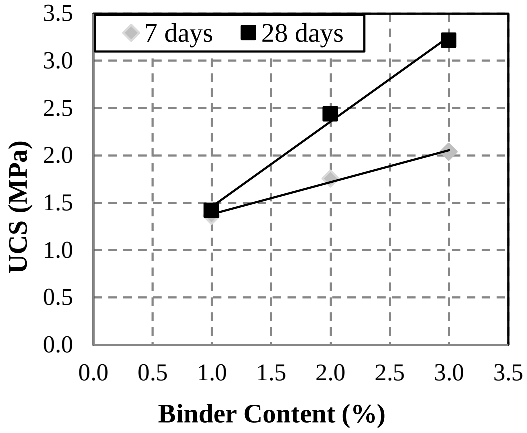

Fig.3 Unconfined compressive strength with respect to varying curing time and percent binder content.

All samples tested, even those stabilized with as little as 1% of a clay-cement binder, possessed unconfined compressive strengths greater than 1 MPa. Clause 1.1.12 in Main Roads Engineering Road Note 9 however, specifies that pavements must not incorporate modified granular materials with a 7 day unconfined compressive strength exceeding 1 MPa [2]. This alone would immediately suggest that this material would not be a viable option to be utilized in pavement structures in Western Australia. With this material having never been previously developed or tested, and with Main Roads specifications primarily developed off empirical methods, it is near impossible to categorize its overall performance off of this alone however.

The 28 day unconfined compressive strength results presented in Fig.3, also enables the classification of the material based off of Austroads' established criteria. This method suggests that samples with 1% binder are modified, samples with 2% binder are lightly bound, and that samples with 3% binder are a heavily bound pavement material [12]. This criterion proposes that the 2% and 3% material admixtures exhibiting bound properties, will be susceptible to unfavorable failure modes such as transverse dry shrinkage cracking. Once again however, with Austroads' classification criteria also based off an empirical approach, it is arduous to classify a material solely based off its 28 day unconfined compressive strength.

In comparison to the base course material presently adopted in Western Australian pavements, HCTCRB, all clay-cement stabilized crushed rock base specimens tested exhibited larger unconfined compressive strengths. With HCTCRB possessing a 28 day unconfined compressive strength of approximately 0.93 MPa, even specimens with as little as 1% clay-cement binder produced a higher compressive strength.

The unconfined compressive strength was not the only performance parameter obtained from these results, with the compressive modulus of the material also determined. Determined as the gradient of the linear sections of the stress-strain curve, the compressive modulus of crushed rock base specimens with varying percent clay-cement binder contents is presented in Fig.4. As this figure displays, there is a linear relationship between the compressive modulus and percent binder additive for clay-cement stabilized crushed rock base, for the binder contents tested in this thesis. That is, for every percent increase in clay-cement binder content, there is also a direct increase in the compressive modulus of the material of approximately 38 MPa. This suggests that whilst additional binder content is increasing the ultimate strength of the material, it is also increasing its ability to undergo smaller deformation rates when compressed, as well as its ability to resist failure phenomena such as shrinkage cracking. This is very beneficial, especially for a pavement base course material.

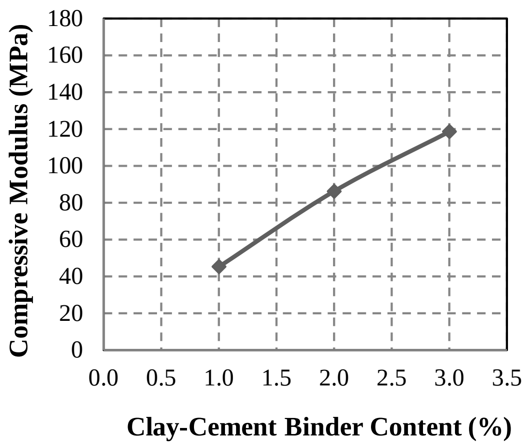

Fig.4 Compressive modulus with varying percent binder content.

Fig.4 also displays how specimens modified with a 1% clay-cement binder possess a very low compressive modulus. This advocates that this material mixture is susceptible to excessive deformation under loading, which can lead to the premature failure of not only the base course layer, but the entire pavement structure. This suggests that whilst the 1% binder content samples developed sufficient unconfined compressive strength, the material mixture would not be a feasible base course material to be utilized in pavement engineering practices due to unfavorable serviceable characteristics.

4.3 Resilient Modulus of Clay-Cement Stabilized Crushed Rock Base

The resilient moduli for crushed rock base specimens at 28 days, stabilized with 1%, 2%, and 3% clay-cement binder contents respectively, is presented in Fig.5. As this figure details, for every increase in percent binder content tested in this thesis, there is a corresponding increase in the resilient modulus of the material. That is, the materials elastic response, or ability to withstand excessive deflections under repeated traffic loading, directly increases with an increase in binder content. This reinforces the information obtained from the unconfined compressive strength and the compressive modulus data. Unlike these two previous sets of data however, the relationship between the resilient modulus and the percent binder content of the material is not linear in nature.

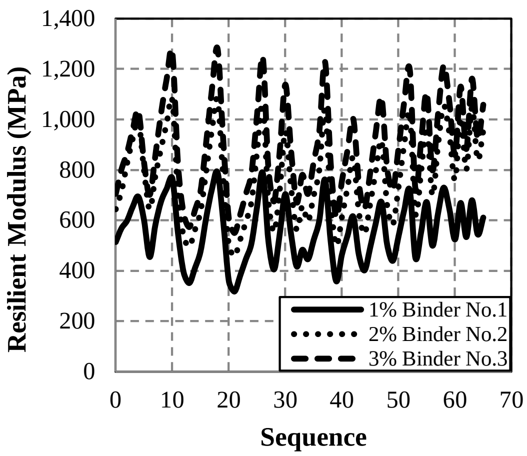

Fig.5 Resilient modulus of varying percent binder content.

In comparison to the peak resilient modulus of HCTCRB of approximately 1130 MPa, the 1% clay-cement binder samples exhibited a significantly lower resilient modulus of only 757 MPa, suggesting that it will be susceptible to greater deflections under the same loading. This reinforces the compressive modulus data obtained for the 1% binder samples, further reiterating that the serviceable characteristics of the material are not sufficient. This further advocates that the performance of a material cannot be characterized off its unconfined compressive strength alone. This is supported with HCTCRB possessing a smaller unconfined compressive strength than the 1% clay-cement binder specimens, however providing a better elastic response to traffic loading.

The 2% and 3% clay-cement binder samples however exhibited larger peak resilient moduli than the HCTCRB, of approximately 1189 MPa and 1277 MPa respectively, purporting that the elastic response of these material admixtures under the same repeated loading is greater. With the 3% clay-cement binder specimens possessing the largest resilient modulus, previous testing data is reinforced, suggesting that this material admixture will exhibit the strongest performance characteristics as a pavement base course layer.

The resilient modulus data also enabled the development of the stress dependent equation of the material, with this parameter further aiding in the identification of a material's performance, denoting whether or not a material will potentially exhibit bound or unbound characteristics. Increasing the applied bulk stress increases the hardening or stiffness of materials, which results in a higher resilient modulus. It is established that bound materials that already exhibit high stiffness', present erratic resilient moduli responses with increased bulk stresses. Therefore with the bulk stresses applied to the specimen plotted against the corresponding resilient modulus, it is established that materials displaying uniform resilient moduli responses with the applied bulk stress state, are potentially exhibiting unbound characteristics [13].

The stress dependent equations for crushed rock base specimens at 28 days, stabilized with 1%, 2%, and 3% clay-cement binder contents respectively, are presented in Fig.6. With uniform resilient moduli data with applied bulk stresses enabling a strong trend line to be developed for all material admixtures, it is suggested that specimens stabilized with 1%, 2% and 3% clay-cement binder contents respectively, are potentially exhibiting unbound characteristics.

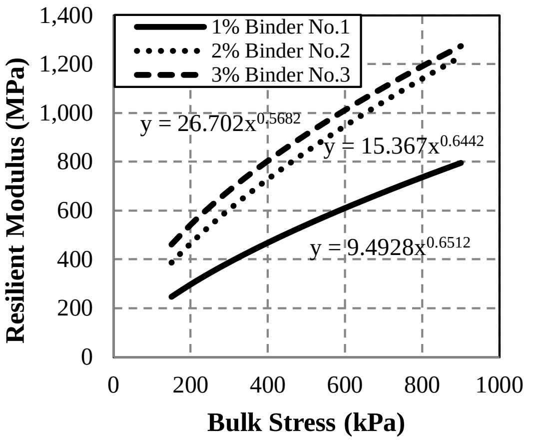

Fig.6 Stress dependent equations of varying percent binder content.

Whilst, in comparison to HCTCRB, the increase in resilient modulus for the 2% and 3% clay-cement binder specimens is not substantial, the most important observation is that both admixtures are potentially exhibiting unbound properties. Whilst HCTCRB also exhibits these properties, an additional hydration phase was required for this, leading to differential performance results due to arduous material mixing and construction procedures.

The most auspicious realization from this research is the fact that the 3% clay-cement binder samples are exhibiting strength characteristics significantly better than HCTCRB, whilst still potentially displaying unbound characteristics. A material's ability to acquire the accompanying strength advantages of a 3% artificial binder, whilst still potentially resisting common failure methods such as shrinkage cracking, suggests that its performance as a base course layer in a pavement structure is very promising.

5. CONCLUSIONS AND RECOMMENDATIONS

With the current base course material in Western Australian pavement structures requiring excessive capital expenditure due to premature pavement failure phenomenon, this paper aimed to present the strength properties of a potential replacement material. A naturally occurring crushed rock base material, stabilized with 3% by dry mass of a clay-cement composite binder, exhibited unconfined compressive strength and resilient modulus characteristics significantly greater than that of HCTCRB. The material also potentially exhibits unbound characteristics, suggesting common pavement failure phenomena such as shrinkage cracking will be mitigated.

However, empirical evidence from Main Roads Western Australia, as well as Austroads, will suggest that this material will be subjected to unfavorable pavement failure mechanisms such as tensile fatigue cracking. Main Roads Western Australia also specifies that this material cannot be incorporated into any pavement structural systems due to these reasons.

Whilst specific strength parameters are sufficient, it is arduous to classify the feasibility of the implementation of a material as a base course layer off this alone. Evidence of this fact is presented with the performance of HCTCRB. Whilst the material possessed adequate strength, it failed due to other mechanisms of stabilizer permanency and moisture susceptibility. Therefore, further investigation is required to determine other key base course performance parameters and to establish the viability of a clay-cement stabilized crushed rock material as a base course layer in Western Australian pavements.

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