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Flexural beam fatigue strength evaluation of crushed brick as a supplementary material in cement stabilized recycled concrete aggregates

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HIGHLIGHTS

- Crushed brick was cement stabilized with recycled concrete aggregate.
- Evaluation of the fatigue life and fatigue modulus of cement stabilized brick blends.
- Flexural beam, Repeated Load Triaxial, unconfined compression and other tests.
- Cement stabilized blends with crushed brick comply with pavement requirements..

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ABSTRACT

In recent years, efforts have been made by various researchers to explore the sustainable use of Construction and Demolition (C&D) materials as a construction material in civil engineering applications. Recycled crushed brick is a commonly found material from demolition activities and works to date on this material in pavement applications have been limited to its usage in unbound pavement layers. This research was undertaken to evaluate the performance of crushed brick as a supplementary material in cement stabilized recycled concrete aggregates. An extensive suite of tests were undertaken on the crushed brick and recycled concrete aggregate blends stabilized with 3% cement. The laboratory evaluation comprised pH, plasticity index, foreign materials content, particle size distribution, linear shrinkage, California Bearing Ratio, modified Proctor compaction, Repeated Load Triaxial test, Unconfined Compressive Strength Test and Flexural Beam Tests. The cement stabilized blends with up to 50% crushed brick content and 3% cement were found to have physical properties, which comply with the local state road authority requirements. The results of Repeated Load Triaxial tests indicated the Recycled Crushed Aggregate/Crushed Brick (RCA/CB) blends performed well with 50% Crushed Brick (CB) content just on the border line for bound pavement material. Unconfined Compression Strengths met the minimum requirement for 7 days of curing for all blends, while the 28 day strength of the blends also improved significantly. The results of the flexural beam tests were noted to be consistent with past works with cement stabilized quarry produced crushed rock products. The modulus of rupture and flexural modulus for all the cement-stabilized blends were found to be consistent with the previous works, which indicate that these blends are suitable for applications such as cement-stabilized pavement subbases. The fatigue life was also within the range that has been previously reported for quarry materials. The cement-stabilized blends with crushed brick as a supplementary material with up to 50% brick content and 3% cement were found to have physical and strength properties, which would comply with road authority requirements.

1. Introduction

Traditional quarry materials for construction are becoming scarce in many developed and developing countries. In recent years, there has been strong environmental move to reduce the expansion of quarries, as our major cities continue to grow, as well as to explore the sustainable use of Construction and Demolition (C&D) materials in construction applications. Significant inroads have been made in recent years in researching the use of C&D materials as a valuable resource in applications such as pavement base/subbase layers, embankments, footpath and other civil

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engineering infrastructure applications. The reuse of these recycled materials in civil engineering infrastructure applications will result in a low carbon solution, considering that recycled materials have significant carbon savings, compared with virgin quarried materials. C&D materials are increasingly being used in pavement applications, particularly as a base/subbase material. C&D materials that have been evaluated and successfully implemented in recent years in roads, footpath and pipe-bedding applications include recycled concrete aggregate [1,2], Crushed Brick [2,3], Reclaimed Asphalt Pavement [4–7], waste rock [8,9] and waste glass [10–13].

In Australia alone, approximately 8.7 million tons of recycled concrete aggregate (RCA) and 1.3 million tons of Crushed Brick (CB) are stockpiled annually [14]. Cement stabilization is a popular option in lightly stabilized pavement bases/subbases in metropolitan roads in major cities worldwide. Approximately 50,000 km of road network is located in metropolitan Melbourne, in the state of Victoria, Australia in which the pavement bases/subbases have been cement stabilized. Traditionally in the past, only high quality cement-stabilized crushed rock has been used for cement-stabilized pavement bases/subbases in Melbourne.

While research has been undertaken in recent years particularly with cement-stabilized reclaimed asphalt pavement in pavements [4], the usage of supplementary materials such as CB in combination with other recycled aggregates has not been studied. Arulrajah et al. [3] reported that recycled CB performs satisfactorily only at low moisture levels and suggested blending recycled brick with binders or other durable recycled materials to enhance its performance in base/subbase applications.

Aside from determination of elastic modulus of cement-stabilized materials, the fatigue properties of cement-stabilized materials are also of importance. Fatigue damage leads to a reduction in modulus of the cement-stabilized layers, thus affecting pavement response [15]. Potential methods that can be used for determining the modulus of cement-stabilized materials include the flexural beam, direct tension, indirect tensile, longitudinal vibration and the direct compression tests [16]. The longitudinal vibration and the direct compression tests have also been attempted but were found to be unsuitable for determining the fatigue properties of cement-stabilized materials [17].

The indirect tensile test and the flexural beam test have been used in past studies [18–21]. However, due to the lack of established test protocols in Australia and other countries to determine the modulus and fatigue properties of cement-stabilized materials, the flexural beam test is the preferred method for evaluation of cement-stabilized granular materials. It was also recognized as a proper design parameter for Australian environment by Austroads [22]. The flexural beam test is a practical test method for the determination of strength, modulus and fatigue life of cement-stabilized materials. The number of load cycles to reduce flexural modulus to half of the initial modulus is an accepted definition for fatigue life of laboratory samples [17]. Flexural beam specimens typically rupture shortly after the number of cycles to attain half the initial modulus is reached. The initial modulus can subsequently be defined as the mean modulus for the first 50 cycles of applied load during the fatigue test. The initial strain is also considered as the mean strain during the first 50 load cycles applied during the fatigue test [17].

The prime objective of this research is to evaluate the performance of CB as a supplementary material with RCA in lightly cement-stabilized pavement base/subbase applications. The development of a laboratory evaluation procedure for these recycled products as a pavement base/sub-base material would result in an increased level of confidence within industry as to their likely in-service performance and appropriate application as well as result in a higher uptake of recycled materials in urban areas where cement-stabilized subbase pavements are commonly used.

2. Materials and methods

Samples of recycled concrete aggregate (RCA) and crushed brick (CB) were obtained from a recycling site in the state of Victoria. RCA and CB used in this study typically comprise graded aggregates up to 20 mm in size. Laboratory tests were undertaken on prepared samples of cement-stabilized RCA blended with various contents of CB (RCA/CB). 3% General Portland (GP) cement was used in the cement-stabilized RCA/CB blends (i.e. 3 g GP cement was added to 100 g of dry RCA and CB blend). The engineering properties of the cement-stabilized RCA/CB blends investigated were: 100% RCA (100RCA), 85% RCA blended with 15% CB (85RCA/15CB), 70% RCA blended with 30% CB (70RCA/30CB) and 50% RCA blended with 50% CB (50RCA/50CB). All the blending percentages are based on dry mass of each material.

The laboratory evaluation was conducted to determine the engineering properties of blends included pH, plasticity index, foreign materials content, particle size distribution, linear shrinkage, California Bearing Ratio (CBR), modified Proctor compaction, Repeated Load Triaxial (RLT) test, Unconfined Compressive Strength (UCS) Test and Flexural Beam Tests.

pH tests were undertaken in accordance with Australian protocols [23]. Both samples consisted of material passing 2.36 mm sieve. Plastic limit, liquid limit and plasticity index tests were undertaken in accordance with Australian standard [24]. Linear shrinkage of RCA and CB were undertaken according to Australian standard test method [25]. To determine the percentage by mass of foreign material in the fraction of RCA retained on a 4.75 mm sieve, visual categorization was carried out according to Victorian state road authority specification [26]. In this method the foreign material (glass, plastic, wood pieces, ceramic etc.) is carefully separated manually from a specified dry mass of RCA and then the ratio between mass of foreign material and mass of initial specimen is reported as foreign material content.

Particle size distribution tests were performed with standard sieves with the aperture sizes of 19 mm, 13.2 mm, 9.5 mm, 6.7 mm, 4.75 mm, 2.36 mm, 1.18 mm, 600 μm, 425 μm, 300 μm, 150 μm and 75 μm [27]. A hydrometer was used to determine the particle size distribution for particles finer than the 75 μm sieve [28].

Modified Proctor compaction tests were undertaken to determine the maximum dry density and optimum moisture content [29]. Soaked CBR tests were performed with samples prepared at their optimum points (Optimum Moisture Content, OMC, Maximum Dry Density, MDD) using modified Proctor compactive effort and tested upon completion of four days soaking condition [30]. Due to high strength of the cement-stabilized blend samples, the CBR test was carried out using a high capacity 250kN universal testing machine.

UCS tests were conducted with samples using split molds to ensure the specimens were not disturbed during removal and parallel end faces were maintained [29,31,32]. UCS specimens were compacted in five layers of pre-determined mass using a Proctor compaction machine and a one-piece split mold (modified compaction as per AS1141.51). A portion of the remaining material was dried in an oven for the determination of moisture content, MC of the sample at the time of compaction. Three specimens of each blend were kept in a fog chamber for a curing period of 7 days. Additionally, four specimens of each blend were kept in a fog chamber for a curing period of 28 days. All samples were subjected to 4 h of immersing in water prior to the UCS test according to Australian Standard test method for UCS [32].

RLT tests were undertaken in accordance with the Australian test protocol [33]. The samples were compacted in a 105 mm diameter mold with the height of 200 mm in 8 layers. Four specimens were prepared for RLT testing with dynamic compaction method [29]. The automatic (mechanical) compaction apparatus, which permits a continuous and even compaction mode, was used to produce uniform specimens to specified density and moisture content. All the specimens were compacted to the target density of 100% MDD and target moisture content of 100% OMC. The specimens were then air dried back to the target moisture of 70% of the OMC. After reaching the target moisture content, specimens were wrapped and left for additional 24 h to assure moisture uniformity within test specimen. The previous experience of authors in RLT testing of C&D material shows that for these coarse aggregates a period of 24 h is more than adequate to ensure uniform moisture distribution in the specimen [3,8]. The moisture contents at different parts of the specimen were measured and found to be similar. The RLT testing procedure consists of a permanent strain test followed by a resilient modulus test. The permanent deformation determination characterizes the vertical permanent strain with multiple loading stages (at different stress conditions) to enable quantification of the effects of vertical stress on permanent strain in a single test. For the cement-stabilized RCA/CB blends, a constant 50 kPa confining stress, and three different loading stages (at specified deviator stresses of 350 kPa, 450 kPa and 550 kPa) were used, each loading stage involved 10,000 repetitions. A trapezoidal repeated deviator stress with a total period of 3 s with rise and fall times of up to 0.3 s and load pulse width of 1 s was used. The resilient modulus determination characterizes the vertical resilient strain response over sixty five stress conditions using combinations of applied dynamic vertical and static lateral stresses in the ranges of 100–500 kPa and 20–150 kPa, respectively. Each stress condition involved 200 load repetitions. The stresses and stress ratios are increased in small increments to avoid early failure, which is probable to occur at high stress ratios. Table 1 summarizes the target (at compaction) and actual (after testing) sample degree of compaction and moisture content values for each specimen for the RLT tests. Generally, it was possible to prepare the specimens within the tolerance of 0.9% for density ratio using the