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Modulus of rupture evaluation of cement stabilized recycled glass/recycled concrete aggregate blends

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HIGHLIGHTS

- Cement stabilization of recycled glass/recycled concrete aggregate blends.
- Evaluation of fatigue life and fatigue modulus of cement stabilized glass blends.
- Flexural beam, Repeated Load Triaxial, Unconfined Compression and other tests.

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ABSTRACT

Construction and Demolition (C&D) wastes are increasingly used as construction material in a range of civil engineering applications. Fine Recycled Glass (FRG) is collected at municipal kerbsides and its usage to date has been limited to unbound pavement layers. This research was undertaken to evaluate the performance of FRG as a supplementary material in blends with cement stabilized recycled concrete aggregate (RCA). Laboratory evaluation was undertaken on the RCA/FRG blends with 10%, 20% and 30% FRG content and stabilized with 3% medium setting General Blend (GB) cement. The laboratory evaluation was comprised of 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 RCA/FRG blends with up to 30% FRG content were found to have physical properties, which comply with the local state road authority requirements. The results of Repeated Load Triaxial tests indicated the RCA/FRG blends performed well with 30% FRG 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 showed a significant improvement with curing. The results of the flexural beam tests were noted to be consistent with past works with cement stabilized virgin quarry rock products. The modulus of rupture and flexural modulus for all the cement-stabilized RCA/FRG blends indicate that these blends are suitable for applications such as cement-stabilized pavement bases/subbases. The fatigue life was also within the range previously reported for quarry materials. The cement-stabilized blends with FRG as a supplementary material with up to 30% FRG content and 3% GB cement were found to have physical and strength properties, which would comply with road authority requirements.

1. Introduction

Traditional quarry-produced materials in civil engineering construction activities are increasingly becoming scarce. This predicament of a lack of natural resources is increasingly encountered in many developed and developing countries, particularly as populations in urban areas continue to grow. The use of quarry materials is furthermore unsustainable from an environmental perspective.

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Increasingly, recycled Construction and Demolition (C&D) aggregates have been accepted as construction materials in civil engineering applications. The use of C&D materials as alternative construction materials will furthermore result in a low carbon solution, considering that recycled materials have significant carbon savings compared with virgin quarried materials. The use of recycled C&D material would greatly reduce the demand for landfill sites and for virgin resource materials by re-using what would be normally regarded as a waste material. C&D materials have been evaluated and successfully implemented in recent years in several countries [1,2]. C&D materials have been trialled successfully in pavements [3–6], footpaths [7] and pipe-bedding [8] applications.

Approximately 50,000 km of road network is present in metropolitan Melbourne, Australia. Cement stabilization of quarry materials, such as crushed rock, has been the traditional option for pavement bases/sub-bases of metropolitan and municipal roads. There is however an increasing impetus from state government sustainability initiatives to use recycled C&D materials where appropriate, particularly as construction materials in civil engineering infrastructure. In Australia, 8.7 million tons of recycled concrete aggregate (RCA) and 1.0 million tons of Fine Recycled Glass (FRG) are stockpiled annually [9]. RCA is commonly obtained from C&D activities while FRG is produced from the glass component of household waste collections.

Modulus of the cement-stabilized materials could decline due to fatigue damage which indicates the significance of studying fatigue properties of cement-stabilized materials [10]. The flexural beam test is suitable for the determination of elastic modulus of cement-stabilized materials [11]. Other tests, such as longitudinal vibration and the direct compression tests have also been attempted, but were found not to be suitable for determining the fatigue properties of cement-stabilized materials [12]. The flexural beam test is the preferred method for evaluation of cement-stabilized granular materials [13–16] and is also recognized as a proper design parameter for Australian environment [17]. The flexural beam test is a practical test method for determining the strength, modulus and fatigue life of cement-stabilized materials. By definition fatigue life is the number of load cycles to reduce flexural modulus of laboratory samples to half of the initial modulus [12]. Flexural beam specimens generally break shortly after reaching to the number of cycles required to attain half of the initial modulus. The initial modulus is subsequently 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 average of strains during the first 50 load cycles applied during the fatigue test [12].

Research in the past on cement stabilized C&D materials in pavement base/subbases has been restricted to reclaimed asphalt pavement [5,18] and recycled crushed brick [19]. In recent years, research has also been undertaken on cement stabilization of contaminated clays and expansive soils [20,21]. This paper will evaluate the performance of FRG as an alternative supplementary material in blends with RCA in cement stabilized pavement base/subbase applications, an aspect that has not been studied previously. Developing a procedure to assess the cement stabilized RCA and FRG blends as a pavement material would result in an increased degree of confidence within industry as to their likely in-service performance and a higher application of them in urban areas.

2. Materials and methods

Samples of FRG and RCA for this study were collected from a recycling site located on the fringe of the city of Melbourne, Australia. The FRG was 5 mm and finer in particle size while the RCA had a maximum particle size of 20 mm.

Geotechnical laboratory tests were undertaken to determine the engineering properties of FRG/RCA blends, with 3% medium setting General Blend (GB) cement. The GB cement comprises a significant percentage of fly ash and slag. GB cement, due to its industrial waste content, is considered as a more environmental-friendly cement compared to traditional Portland cement and as such was used in this research work. The laboratory evaluation included pH, plasticity index, foreign materials content, particle size distribution, hydrometer, linear shrinkage, California Bearing Ratio, modified compaction, Repeated Load Triaxial (RLT), Unconfined Compressive Strength (UCS) and flexural beam tests. The engineering properties of the cement stabilized RCA/FRG blends evaluated were: 90% RCA blended with 10% FRG (90RCA/10FRG); 80% RCA blended with 20% FRG (80RCA/20FRG) and 70% RCA blended with 30% FRG (70RCA/30FRG). For comparison and control purposes, the laboratory results of the FRG/RCA blends were compared with previous reported results of a 100RCA materials stabilized with 3% rapid setting General Portland (GP) cement [19].

pH tests were performed on the RCA/FRG blends, prior to the addition of cement, and in accordance with Australian Standard [22]. RCA consisted of material passing 2.36 mm sieve. Plastic limit, liquid limit and plasticity index tests were performed in accordance with Australian standard [21,23]. Foreign material content was visually identified to determine the percentage by mass in the fraction of a crushed concrete product retained on a 4.75 mm sieve [24].

Particle size distribution tests were undertaken on the RCA/FRG blends, prior to the addition of cement, using Australian 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. [25]. The minimum amount of 3 kg was sieved and the particle size distribution was plotted for each blend.

Modified compaction tests were performed to determine the maximum dry density and optimum moisture content [26]. California Bearing Ratio (CBR) tests were performed on samples prepared at optimum moisture content using modified compactive effort at 100% maximum dry density (MDD) being soaked for four days [27].

Unconfined Compressive Strength (UCS) tests were conducted according to Australian standard [28]. Samples were prepared fully in accordance with the methods of testing soils for engineering purposes [26,29] using split molds to ensure that UCS samples were not damaged during removal and parallel end faces were maintained. UCS samples were compacted in five layers of pre-determined mass using a Proctor compactor and a one-piece split mold. A portion of the remaining material was dried in an oven for the determination of moisture content of the sample at the time of compaction. Compacted samples were immediately taken to the fog chamber for curing. Seven-day samples (four sets of four specimens) were kept in the fog chamber until the time of testing. Simultaneously additional samples (four sets of four specimens) subjected to longer curing periods were kept in the fog room for 28 days. All samples were subjected to 4 h of immersion in water prior to the UCS test. The water/cement ratio of UCS samples was kept at a maximum value of 3.5 in order to be consistent with the common practice of industry in Australia.

The Repeated Load Triaxial (RLT) tests were undertaken using the method specified by Austroads [30]. The samples were compacted at optimum moisture content (OMC) to the target density of 100% MDD in a 105 mm diameter mold with the height of 200 mm in 8 layers. The samples were then dried back to approximately 70% of the OMC prior to testing. Five specimens were prepared for RLT testing with dynamic compaction effort as specified by Australian standard [26]. The automatic (mechanical) compaction apparatus, which allows a continuous and even compaction mode, was used to produce uniform specimens to a specified density and moisture condition. The procedure of RLT testing consists of a permanent strain test followed by a resilient modulus test. The former 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 blends, 50 kPa confining stress, three different loading stages (at specified deviator stresses of 350 kPa, 450 kPa and 550 kPa, respectively) were used, and each loading stage involved 10,000 repetitions. A confining stress of 50 kPa was applied for all loading stages. The resilient modulus determination characterizes the vertical resilient strain response over 65 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 sizes to avoid early failure, which can occur at high stress ratios.

Flexural beam test involves 3 stages of testing to determine modulus of rupture (flexural strength), flexural modulus and fatigue life of the cement stabilized materials. One pair of beams for each blend (5 pairs in total) was prepared at an external laboratory facility. Flexural strength was subsequently determined in accordance with Australian standard [31]. Flexural modulus and fatigue life were determined in accordance with Yeo et al. [12]. In order to compact the slabs a rectangular mold with internal dimensions of 400 mm long × 320 mm wide × 145 mm high was used along with a slab compactor. The compacted slabs were kept in the mold and covered with a wet cloth and lid to minimize moisture loss and stored at 23 °C for a minimum of 2 days before removing from the mold. The slabs were then placed back in fog chamber for further curing of 14 days to ensure the slab becomes strong enough to be cut. Then each slab was cut into two beams. All the beams were cured in fog room for a total of 28 days. Upon completion of curing, the fatigue testing was conducted in a controlled stress mode. This was considered the most appropriate simulation of normal repetitive wheel loads, particularly for a given Accelerated Loading Facility experiment at a given axle load [12].

In accordance with Yeo et al. [12], the first beam of the same slab (Beam A) was used to determine the peak load required to break the beam using the Modulus of