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Physical properties and shear strength responses of recycled construction and demolition materials in unbound pavement base/subbase applications

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HIGHLIGHTS

- Construction and Demolition (C&D) materials are increasingly used as construction materials.
- Evaluation of the shear strength characteristics of C&D materials.
- Direct shear, triaxial, unconfined compression and other strength tests were undertaken.
- Shear strength of the C&D materials were compared.
- C&D materials found to be suitable for various construction applications.

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ABSTRACT

Construction and Demolition (C&D) materials are increasingly used as construction materials in engineering applications. Their usage currently includes applications such as pavements, ground improvement, engineered fills, pipe bedding, backfill and aggregates in concrete. A comprehensive laboratory evaluation of physical and shear strength characteristics of recycled C&D materials was undertaken using gradation, Los Angeles Abrasion, unconfined compression, California Bearing Ratio (CBR), direct shear and consolidated drained triaxial tests. The recycled C&D materials evaluated were recycled concrete aggregate (RCA), crushed brick (CB), reclaimed asphalt pavement (RAP), waste excavation rock (WR), fine recycled glass (FRG) and medium recycled glass (MRG). All the recycled C&D materials are classified as well-graded materials and their compaction curves are controlled by water absorption and surface characteristics. RAP, FRG and MRG exhibit flat compaction curves while RCA, WR and CB exhibit bell-shaped compaction curves. The shear responses of the recycled C&D materials are classified into two groups: dilatancy induced peak strength and dilatancy associated strain-hardening behaviors. RCA, WR and CB are dilatancy induced peak strength materials in that their peak strength is clearly observed after the maximum dilatancy ratio occurs. Higher dilatancy ratios in these materials are associated with higher peak friction angles. RAP, FRG and MRG on the other hand are dilatancy associated strain-hardening materials, which exhibit strain-hardening behavior even with a relatively high magnitude of dilatancy. Based on the evaluation of the shear strength characteristics, it is ascertained that the compacted C&D materials have the potential to be used in pavement base/subbase applications as they have the required minimum effective friction angles. RCA, CB and WR in particular are found to also meet the physical and shear strength requirements for aggregates in pavement base/subbase applications.

1. Introduction

Recent generation of large amounts of solid waste produced all over the world has imposed significant pressure on the environment with the majority of solid wastes produced by the

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construction and demolition sectors [1–5]. Construction and Demolition (C&D) materials, generated by various construction and demolition activities are normally referred to as solid wastes. Construction waste is defined as solid wastes from the construction, remodelling and repairing of individual residences, commercial buildings, and other civil engineering structures [6,7]. Demolition wastes are generally defined as the wastes from demolished buildings and roads [8–10].

The traditional method of managing C&D waste materials has been by disposal into landfill [4]. However, recycling and reuse of C&D materials has become a topic of global concern and in recent decades, it has been recognized that C&D and other waste materials volumes are increasing annually and account for a large proportion of waste materials present in landfills [11–16]. Various researchers have evaluated the sustainability of C&D waste materials in various civil engineering applications such as pavement, ground improvement, pipe-bedding and concrete applications [17–24]. With the increasing use of coarse granular recycled C&D materials in civil engineering applications, a thorough understanding of their shear strength characteristics is required to enable their usage in these engineering applications.

This paper investigates the physical and shear strength characteristics of six common C&D materials and assesses the viability of using these C&D materials in pavement base/subbase applications. The six recycled C&D materials studied were recycled concrete aggregate (RCA), crushed brick (CB), reclaimed asphalt pavement (RAP), waste excavation rock (WR), fine recycled glass (FRG) and medium recycled glass (MRG).

The physical and shear strength characteristics of the recycled C&D materials were obtained from several test methods being gradation, compaction, Los Angeles (LA) Abrasion, California Bearing Ratio (CBR) and Unconfined Compression Strength (UCS) tests. The shear strength parameters for two modes of failures, direct shear and compression, were also investigated using Direct Shear Test (DST) and Consolidated Drained (CD) triaxial tests. In order for C&D materials to be used in pavement base/subbase applications, the C&D materials must meet local road authority requirements based on these basic and advanced tests in order to ensure the physical and shear strength properties are equivalent to that of traditional quarry materials. The shear strength and durability properties are typically assessed from CBR, LA, UCS, DST and CD tests.

The failure envelopes in terms of total stress from DST results and in terms of effective stress from CD triaxial test results are presented in this paper. In practice, the DST on the compacted samples at Optimum Water Content (OWC) is generally performed and the obtained total strength parameters are used for geotechnical design due to its simplicity and low cost even though the samples are in not fully saturated state. Triaxial test on compacted samples in fully saturated state is more complicated but the shear strength parameters obtained is more conservative for design purpose as matric suction does not play a role in shear strength of aggregates. The details of the material tested, testing method, apparatus and results are presented in this paper. The shear responses and shear strength parameters of the recycled C&D materials are then analyzed and discussed. This paper is expected to provide a contribution to various parties interested in the usage of recycled C&D materials, inclusive of end-users, designers, contractors and consultants alike as these properties are fundamental in the design and construction of various engineering applications.

2. Materials

This research investigated physical and shear strength characteristics of six different recycled C&D materials by using various laboratory testing apparatuses. These recycled C&D materials are RCA, CB, RAP, WR, FRG and MRG.

RCA is a by-product of construction and demolition activities of concrete structures. Concrete chunks are crushed into aggregates of variable sizes depending on the field of application. Engineering properties of RCA have been reported by Tam and Tam [25]; Gomez-Soberon [26]; Poon and Chan [23]; Courard et al. [27]; Arulrajah et al. [28] and McKelvey et al. [22]. RCA samples were obtained from a recycling facility in the state of Victoria, Australia and had a maximum particle size of 20 mm.

CB is a by-product of construction and demolition activities of buildings and other structures. CB typically consists of 70% brick and 30% other materials such as asphalt, concrete and rock. CB samples were obtained from a recycling facility in the state of Victoria, Australia and had a maximum particle size of 20 mm. Select properties of CB material in pavement sub-base applications has been reported by Arulrajah et al. [29].

Asphalt is removed from roadways on a regular basis, leading to excess stockpiles of spent asphalt. This material will end up in landfills without a sustainable method to reutilize it. RAP is the name given to asphalt that has been repurposed. Taha et al. [30]; Puppala et al. [14,31], Hoyos et al. [11] and Arulrajah et al. [32] have described the field and laboratory performance of RAP. RAP samples for this research were obtained from a recycling facility in the state of Victoria, Australia and had a maximum particle size of 20 mm.

Waste excavation rock (WR) used in this study originates from basalt floaters or surface excavation rock (basalt), which commonly occurs near the surface to the west and north of Melbourne, Australia. Several authors have reported on the engineering properties of various other WR in pavement subbase applications [33–35]. WR samples were obtained from a recycling facility in the state of Victoria, Australia and had a maximum particle size of 20 mm.

Waste glass is a mixture of different coloured glass particles and often comprises a wide range of debris (mainly paper, plastic, gravel, metals, and food wastes). It is the result of crushing the waste glass collected from residential and industrial areas and is mostly obtained from kerbside collection of packaging glass containers and bottles. The presence of different coloured glass and diverse types of debris are the primary obstacle in reusing recycled glass in the bottle production industry. fine recycled glass (FRG) with a maximum particle size of 4.75 mm and medium recycled glass (MRG) with a maximum particle size of 9.5 mm are the main types of recycled waste glass available in the state of Victoria, Australia. Select engineering and environmental properties of waste glass in road and footpath applications have been described by several authors [36,37].

3. Experimental methodology

For the laboratory experimental works, the tests were conducted by either the Australian standards or other reputable international standards such as ASTM standards. The preference was to adopt the Australian standards and in the event a test standard was not available for a certain test, the ASTM standards were adopted. Furthermore, some equipment and softwares in the laboratory were procured from the United States, in which event the ASTM standards were preferred for compatibility purposes.

3.1. Los Angeles Abrasion tests

The Los Angeles Loss degradation test is a widely specified test for evaluating the resistance of aggregates to abrasion and impact forces [38]. LA abrasion loss tests were conducted on all sources by the ASTM [39] test method. This test has been widely used as an indicator of the relative quality or competence of various sources of aggregate having similar mineral compositions.

3.2. Modified compaction tests

To determine the dry density–moisture content (DD–MC) relationships, modified compaction tests were conducted on the recycled materials by following the Australian standard [40], which is similar to that of ASTM [41]. It is noted that the sample was compacted in five layers in a 105 mm diameter by 115 mm high mold with the application of 25 blows per layer for the compaction testing, and the DD–MC relationships were determined for a compaction effort of 2703 kN m/m^3.