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Key performance properties of asphalt mixtures with recycled concrete aggregate from low strength concrete

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HIGHLIGHTS

- Testing the physical and mechanical properties of recycled concrete aggregate (RCA) produced from low strength concrete.
- Evaluating the key performance properties of asphalt concrete with various levels of the RCA replacements.
- Analyzing the possibility of hot mix asphalt (HMA) concrete with RCA from low strength concrete.
- The HMA concrete containing up to 50% RCA from low strength concrete can be satisfactorily used in road construction.

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ABSTRACT

Recycled concrete aggregate (RCA), recycled from low strength concrete, was used to replace the coarse natural aggregate (NA) at different replacement levels. The results indicate that compared with NA, the RCA used had lower apparent relative density, crushing and wearing value, higher water absorption, poorer adhesion to asphalt. As the RCA replacement level increased, the high temperature stability and the low temperature cracking resistance of the asphalt concrete generally increased; the water stability is significantly lower than that of the asphalt concrete made with NA; the asphalt concrete containing up to 50% RCA can be satisfactorily used in road construction.

1. Introduction

Recycled concrete aggregates (RCAs) are increasingly used to replace natural aggregates in construction materials due to various environmental considerations [1–2]. RCA particles generally consist of two parts: a particle of natural aggregate (NA) and a layer of old concrete mortar adhered on the NA particle. Chemically, the adhered mortar of RCA is much more reactive than NA and often contaminated with debris, thus having significant effects on the bond and chemical interactions between the RCA and other materials. The chemicals lixiviated from the adhered mortar have also caused great concerns for new material properties and environments [3–4]. Physically, the adhered mortar of RCA is usually more porous than NA, and it governs the physical properties (e.g., density, porosity, and water absorption) of the RCA [5]. However, the mechanical properties (e.g., crashing and anti-wear resistances) of RCAs are commonly equal to or better than NA [6–7], which provides a great opportunity for their reuse.

Properties of RCAs vary extensively because they are closely related to the mix proportions, strength grade, duration of usage, and exposure conditions of their parent concrete [8]. Therefore, RCAs must be carefully characterized before reuse, and their chemical and physical characteristics as well as their effects on new construction materials shall be considered in the new material mix design and processing [9].

Since the overall quality of RCAs is generally lower than that of NA, RCAs are often used to partially replace NA in the production of new construction materials. Depending up the quality of a RCA, the level of the RCA replacement shall be properly determined so as not to have significant negative effects on the properties of the new materials.

Recently, increasing studies have been conducted on use of RCAs in hot-mix asphalt (HMA) [10–11]. It is believed that as RCA particles are coated with a layer of asphalt, the problem

Abbreviations: RCA, recycled concrete aggregate; NA, natural aggregate; HMA, hot mix asphalt; SEM, scanning electron microscope; VMA, voids in mineral aggregate; VV, void volume; DS, dynamic stability; MS, Marshall stability.

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associated with the lixiviation of chemicals from RCA can be eliminated. Research has indicated that RCAs produced from most conventional concrete are generally suitable for use in HMA for flexible pavement constructions [5]. However, little studies are reported on the performance of asphalt concrete containing RCA produced from low strength concrete (Strength grade is lower than C30). The present study is to fill up this gap.

In the present study, the physicochemical and mechanical properties of RCA produced from a low strength concrete of a building foundation were firstly characterized. The key performance properties of asphalt concrete with various levels of the RCA replacements were evaluated. The results are expected to provide engineers with an insight onto design and construction of HMA containing low grade RCAs.

2. Test and analysis of the characteristic of RCA used

Two types of aggregates were used in the present study: (1) RCA produced from the old building foundation concrete on the twentieth Century 80s, its strength was equivalent to C20, and the coarse aggregate was comprised with pebbles. The production process of RCA were the pretreatment, crushing, grinding, screening and washing, and (2) NA is made from granite. The properties of the RCA and NA, such as apparent relative density, water absorption, crushed value, Los Angeles wear value, and the adhesion, were evaluated according to the Chinese standard [12]. The detailed test methods and results are described as below.

2.1. Aggregate sampling

The RCAs used in the present study were screened into three different sizes: (4.75–9.50 mm, 4.75–13.2 mm and 9.50–19.0 mm,) with the same processing method. After transported into the lab, the RCA was sampled using the four-point method, where a portion of received RCA was firstly piled into a cone, and though the center, the cone sample was split into four equal parts. Two of the four parts were arbitrarily selected to form a new small cone, and it was split according to the above-mentioned method again and again, until the remaining two portions reached the required sample quantity. After sampling, the aggregates were sieved with 4.75 mm standard sieve and then rinsed with water to ensure that they are free of dirt and dusts (Fig. 1).

2.2. Aggregate characteristic tests

2.2.1. Density and absorption tests

Density and absorption of the aggregate were determined according to the Chinese national standard (JTGE42-2005) using Eqs. (1) and (2), where, γ_a is the apparent relative density, ϖ_x is the water absorption rate, m_a is the oven dry weight, m_f is the surface dry weight, and m_w is the wet weight of the tested aggregate.

$$\gamma_a = m_a/(m_a - m_w) \quad (1)$$

$$\omega_X = (m_f - m_a)/m_a \times 100 \quad (2)$$

Because the surfaces of RCA contain dust and mortar, the RCA was soaked and rinsed for a little longer time about 1 h than NA.

2.2.2. Crashing value tests

In the test, the aggregate sample passing through 12.5 mm and retained on 10 mm IS Sieve was oven-dried at a temperature of 212 °F for 4 h. It was then placed in a cylinder of the testing apparatus in 3 layers, and each layer was consolidated 25 times with a tamping rod. After the consolidation and leveling of the top surface, the weight of the aggregate sample was measured (Weight A). The sample was then placed on a compression testing machine and loaded at a uniform rate so as to reach 400 kN in 10 min. After holding the load for 5 min, the load was released. The crashed sample was then sieved through a 2.36 mm IS Sieve and the fraction passing through the sieve was weighed (Weight B). The aggregate crushing value is expressed as the ratio of (B/A) * 100%. Two tests were conducted for each aggregate studied.

2.2.3. Abrasion tests

The abrasion values of the aggregates were determined by the Los Angeles abrasion machine. In the test, 2500 g of aggregate sample (m1), with a size range of 4.75–9.5 mm and 9.5–16 mm, was mixed with 8 steel balls, with the total mass of 3330 ± 20 g, in a rotational drum at a rotation speed of 30–33 r/min for 500 revolutions. Then, the fines of the sample was sieved with a 1.7 mm (No. 12) sieve. The portion of an aggregate sample retained on the sieve was rinsed and oven dried at a temperature of 221 °F for 24 h. After cooling at a room temperature for 4 h, the mass of the aggregate sample is measured as m^2. The percentage ware of the aggregate is expressed as $[(A - B)/A] \times 100$. The arithmetic mean value of two test results, with a difference less than 2%, is accepted as the final test result.

2.2.4. Adhesion to asphalt tests

The adhesion of aggregate to asphalt, which is directly affected by the acidity and alkalinity of aggregate, to a great extent decides the physical and mechanical property of mixture. And the stronger the alkalinity, the better the adhesion. According to the specification, the adhesion property of aggregate can be tested by water-boiling method. First, four 13.2–19.0 mm aggregate particles were shaped close to a cube shape, fastened at the center of the cube in a line. The cubic specimens were then placed in 221 ± 41 °F oven for 1 h. After drying, they were submersed into asphalt at 248 ± 50 °F for 45 min. After being taken out from the asphalt, the sample is

(a) RCA as received (b) RCA after cleaning and sieving

Fig. 1. RCA before and after washing.