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Sustainable roadway construction using recycled aggregates with geosynthetics

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ABSTRACT

Concrete, asphalt pavements, and ballast are removed during the re-construction of existing roads and have been increasingly recycled as aggregates for the construction of roadways. Due to existence of asphalt, cement, and fines, mechanical properties of recycled aggregates may not be sufficient for load support. They may also have long-term durability problems. Geosynthetics have been used to improve mechanical properties and long-term durability of recycled aggregates. This paper reviews recent research work on the use of geosynthetics to stabilize recycled aggregates in roadway construction and summarizes the main findings on permanent deformation, creep deformation, degradation, stress distribution, and/or crack propagation.

1. Introduction

According to the Federal Highway Administration (FHWA, 2004), two billion tons of aggregates are quarried annually in the United States and the quantity of quarried aggregates will reach 2.5 billion tons by 2020, which force construction industries to consider new sources of aggregates. Roadways (highways and railways) that have reached the end of their service lives are frequently rehabilitated by removing the existing roadway surfaces and replacing the removed portion with new construction materials. A large amount of recycled aggregates are created every year during the rehabilitation and reconstruction of existing roadways. Currently, great emphasis is placed on sustainable construction and infrastructure with green technologies because the demand for sustainable and environmental-friendly roads is increasing daily. More technologies for sustainable roadway construction are needed. One way to construct sustainable roads is through the use of recycled aggregates. Recycled Asphalt Pavement (RAP), Recycled Concrete Aggregate (RCA), and Recycled Ballast (RB) are the three types of recycled aggregates as shown in Fig. 1 and are discussed in this paper.

According to the Recycled Material Resource Center (RMRC, 2008), RAP is a removed and reprocessed pavement material from deteriorated asphalt pavements containing asphalt binder (3–7%) and aggregates (97–93%) by weight. The use of RAP has been in practice since 1930s. The U.S. FHWA estimated that 100.1 million tons of asphalt pavement materials are milled off each year during resurfacing and widening of road projects, of which 80.3 million tons are reclaimed and reused for roadbeds, shoulders, and embankments (Missouri Asphalt Pavement Association, 2010). RCA is a removed and reprocessed construction material from demolished concrete structures, such as high-rise buildings, bridges, highways, railways, etc. containing cement and natural aggregates. The natural aggregates contain 60–75% of the total volume of RCA (RMRC, 2008). Ballast is a free-draining granular material composed of medium to coarse gravel-sized aggregates (10–60 mm in diameter) with a small percentage of cobble-sized particles, commonly used as a load-bearing material in railway tracks (Indraratna, Khabbaz, Salim, & Christie, 2006). The good quality of ballast consists of angular particles with rough surface and minimum hairline cracks and should have high specific gravity, shear strength, toughness and hardness, and enough resistance to weathering (Indraratna et al., 2006). Railway ballast degrades and deteriorates progressively under repeated cyclic loading. Degraded ballast is usually replaced by fresh ballast during routine track maintenance. The railway track constructed using recycled ballast (RB) shows excessive settlement and lateral deformation, which affect the performance of railroads.

The use of recycled aggregates can reduce the cost of construction materials, reduce the amount of waste to be land-filled, reduce the transportation and energy costs to import virgin aggregates, and conserve natural resources by requiring less virgin aggregates in road construction projects. Several agencies are seriously considering the economic and environmental benefits of using recycled aggregates in roadways and facing challenges to maintain

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(a) RAP **(b)** RCA **(c)** RB

Fig. 1. Types of recycled aggregates.

high-quality road infrastructure. The mechanical properties (mainly strength and stiffness) and long term durability (breakage and abrasion) of recycled aggregates may not be sufficient for load support due to the existence of asphalt and cement, or loss of angularity of ballast. In the past, most of the research studies on the improvement of RAP and RCA quality focused on blending them with virgin aggregates or stabilizing them using chemical additives. However, the blending of RAP and RCA with virgin aggregate still consumes natural resources and the chemical stabilization is not always environmental friendly.

The use of 100% recycled aggregate with geosynthetic is a sustainable solution. Liu, Scarpas, Blaauwendraad, and Genske (1998) were few early researchers to explore such a possibility. Recent research work done by Indraratna, Salim, and Christie (2002), Indraratna et al. (2006), Han et al. (2011), Thakur, Han, Pokharel, and Parsons (2012), Thakur, Han, and Parsons (2013), and others has further evaluated the behavior and performance of geosynthetic-reinforced recycled aggregates. This paper reviews these studies on the use of geosynthetics to stabilize recycled aggregates (RAP, RCA, and RB) in roadway construction and summarizes the main research findings.

2. Reinforcement mechanism of geosynthetic

Geosynthetics manufactured from polymeric materials have been widely used as construction materials to solve many civil engineering problems since 1970s. Geosynthetics are used to improve the performance of unpaved and paved roads for over 40 years (Giroud & Han, 2004). The use of geotextile, geogrid, and geocell with recycled aggregates are discussed in this paper. Geotextile and geogrid are planar geosynthetics whereas geocell is a three-dimensional honeycomb type of geosynthetic. Geogrid and geocell improve the performance of aggregate layers by providing lateral confinement whereas geotextile improves the performance of aggregate layers by providing a tensioned membrane effect. Different types of geosynthetics used in roadway construction are shown in Fig. 2.

The most efficient and convenient location of geosynthetic in roadway construction is at the interface of subgrade and granular base course (Das & Shin, 1998). Geosynthetic installed at this location provides full or partial separation, lateral confinement of granular base materials, a tensioned membrane or beam effect when a road deforms extensively. The tensioned membrane or beam effect is referred to as the tension developed in the curved geosynthetic-reinforced base to resist the vertical load (Rajagopal, Krishnaswamy, & Madhavi Latha, 1999). The tensioned membrane effect mechanism is shown in Fig. 3a. Nonwoven geotextile provides separation, filtration, and drainage whereas woven geotextile provides separation and reinforcement. Geogrid and geocell provide reinforcement to aggregate base and subgrade by providing lateral confinement due to their tensile strength and stiffness. Uniaxial, biaxial, and triaxial geogrids are three types of geogrids available in the market. Uniaxial geogrid provides tensile resistance in only one direction, biaxial geogrid provides tensile resistance in two directions, and triaxial geogrid can provide near-uniform tensile resistance (Dong, Han, & Bai, 2010; Qian, 2009) when it is subjected to tension in different directions. Qian (2009) reported that the confinement of granular base aggregates was obtained through the interlocking between geogrid apertures and aggregate particles as shown in Fig. 3b. Webster (1992) reported that the degree of interlocking depended on geogrid aperture size and aggregate particle size and the effectiveness of interlocking depended on the in-plane stiffness, rib strength, and junction strength of the geogrid. Thakur et al. (2012) reported that the geocell-reinforced bases had improved bending resistance. The beam effect of geocell-reinforced bases is demonstrated in Fig. 3c.

3. Geosynthetic-reinforced recycled asphalt pavement (RAP)

Geotextile, geogrid, and geocell have been used to stabilize RAP bases. This section discusses the effects of geosynthetic reinforcement on the permanent deformation, resilient deformation, creep deformation, and stress distribution of RAP bases.

Foye (2011) presented the work of a design-build contractor who used a geosynthetic stabilization technique for reconstruction of 19,500 m^2 asphalt parking lot on a site with very weak subgrade (CBR ranging from 1 to 3%). The remedial design parking lot section consisted of very weak subgrade soil overlaid by 200 mm thick geocomposite (a 271 g/m^2 needle-punched nonwoven geotextile – geogrid)-stabilized blended RAP aggregate base, 64 mm thick dense-graded asphalt course, and 25 mm thick asphalt wearing course. The geocomposite was placed at the interface of subgrade and granular base course to provide separation and reinforcement. It was found that the geocomposite-stabilized parking lot section showed little rutting or deflection under proof rolling and the use of the geocomposite reduced the cost of construction from about $890,000 (estimated for the original cut and replacement specification) to about $200,000. In addition, the geocomposite stabilization technique saved time, resources, and energy as compared with the traditional cut and replacement technique.

Han et al. (2011) conducted moving wheel tests on five geocell-reinforced and two unreinforced RAP bases over weak subgrade (target CBR = 3%) to evaluate the effect of geocell reinforcement on rut depth and stress distribution angle at a certain number of passes of the wheel load. Two types of recycled asphalt materials, named RAP and FRAP (fractioned RAP or RAP with finer gradation) were used in this study. The following base sections were prepared and tested:

(1) 300 mm thick unreinforced RAP.
(2) 150 mm thick geocell-reinforoced RAP with a 20 mm thick RAP cover.

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