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Laboratory investigations of activated recycled concrete aggregate for asphalt treated base

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HIGHLIGHTS

- We analyze the mineral composition of RCA and observe surface morphology by SEM.
- We select the best activator out of three used to activate RCA.
- We prove that substituting natural aggregate by RCA in ATB is feasible.

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ABSTRACT

Asphalt treated base ATB-25 was designed containing recycled concrete aggregate (RCA), which was pretreated with three types of activators in various amount. Crushed value, water absorption, density and adhesion with asphalt of RCA were tested. Four mixtures of ATB-25 were designed containing different contents of RCA: 0%, 30%, 60% and 100%. Marshall test, rutting test, water stability test and low-temperature bending test were conducted to evaluated road performances of above mixtures. It was found that the voids and microfractures existing in RCA led to large water absorption and crushed value and low density and strength. Application of activator effectively decreased crushed value and water absorption and enhanced adhesiveness with asphalt due to closing of voids in RCA. The activation effect of organic silicon resin was superior to that of metatitanic resin acceptor and silane resin acceptor. Because of asphalt absorption by microfractures, asphalt content and oil absorption of ATB increased as RCA content increasing. While effective asphalt content of different mixture were basically the same, indicating that RCA and natural aggregate had the same effective thickness of asphalt film. Residual Marshall Stability, tensile strength ratio and low-temperature bending strain of ATB decreased with RCA content increasing. Low-temperature bending strain decreased to 1728.5με when RCA content increased to 100%, which was less than the required value of specification of China. No obvious relationship was found between dynamic stability and RCA content, but dynamic stability of all ATB mixtures containing RCA satisfied the requirement in specification of China. ATB-25 mixtures containing less than 60% of RCA satisfied all the requirements of specification of China.

1. Introduction

Construction and demolition of civil engineering produce abundant construction waste. At present, China is undergoing a construction boom, about 2 billion tons of construction waste was produced every year, of which more than 70% was waste cement concrete [1]. With China's rapid development of urbanization and urban construction in the future, the proportion will be further increased in the next 50 years. Moreover, except for cause casualties and property losses, large amount of construction waste is also produced by earthquake and other natural disasters. Wenchuan earthquake, which occurred on May 12, 2008 and had a magnitude of 8.0, damaged most of the buildings in disaster-stricken area and produced about 380million tons of construction waste. Most of the construction waste was abandoned except a little part of them was used in post-disaster reconstruction for wall building and embankment filling [2,3]. Although governments at all levels in China encourage recycling of waste materials, due to various reasons, lots of construction waste is still directly shipped to city suburbs, disposed by means of stacking in the open or

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simple landfill. These dispose means not only occupies plenty of lands, but also pollutes environment [4]. On the other hand, with China's highway construction developing dramatically, a large number of high-quality aggregates, such as basalt, granite and limestone is needed, especially in pavement construction. However, heavy use and distribution imbalance cause rise in price, which has once increased to 100–150RMB per ton. Short supply of high-quality aggregate influences construction progress, and enhances construction cost as well [5]. Experts have predicted that short of high-quality rock will be the main problem of pavement construction in China.

Therefore, partially substituting construction waste for natural aggregate can not only mitigate short supply of natural aggregate, but also help to dispose construction waste at the same time. Recycled Concrete Aggregate (RCA) refers to aggregate produced by cement concrete in construction waste through a series of procedures including sorting, reinforcement removing, crushing, and grading. Size of RCA is commonly less than 40 mm, it can be classified into coarse RCA ($\geqslant$4.75 mm) and fine RCA(<4.75 mm) by size. Since the end of world war II, developed countries started the study on recycling of construction waste. RCA was used in the construction of base course, shoulder and subgrade, but hardly used in asphalt mixture. The characteristics of RCA, including low density, large void, low strength and high water absorption restrict its use in asphalt mixture. Comparing to cost of transportation and processing, the application of construction waste in subbase and base course cannot add its value. To make its value truly reflected, application in asphalt pavement is expected. In order to use RCA in pavement construction, however, RCA must be activated so as to decrease water absorption and enhance strength.

In this paper, Asphalt treated base ATB-25 was designed adopting recycled concrete aggregate (RCA), which was pretreated with three types of activators in various volume. Crushed value, water absorption, density and adhesion of recycled concrete aggregate were tested. Four mixtures of ATB-25 were designed containing different contents of RCA: 0%, 30%, 60% and 100%. Marshall test, rutting test, water stability test and low-temperature bending test were conducted to evaluated road performances of above mixtures.

2. Review of literature

2.1. RCA activation

Shortcomings of RCA cover microfracture, large void, high water absorption, low bulk density and high crushed value. In order to satisfy requirements for aggregates in asphalt mixture, strengthening or activation is needed. Normally, there are two types of strengthening methods: physical strengthening and chemistry strengthening. Amnon [6] used ultrasonic cleaning and silica fume treatment method to activate RCA. Ultrasonic cleaning method increased strength of RCA and bonding between cement and RCA through cleaning loose hardening cement mortar particles with ultrasonic, leading to an increase of 7% in compressive strength at ages 7 and 28 days. In the silicon fume treatment method, silicon fume reacts with calcium hydroxide, hydration product of cement, to form dense membrane, which wraps around RCA and enhances its strength. Compressive strength at ages 7 and 28 days were increased by 30% and 15%, respectively. Xiao [7] adopted acid socking process to eliminate the loose hardening cement mortar particles and increase its strength and workability. This method is relatively expensive. Cheng [8] soaked RCA in sodium silicate solution of 3% concentration for one hour, the compressive strength of RCA concrete was increased significantly. The microbial carbonate precipitation (MCP) for RCA surface treatment was studied by Qiu and it is proved to effectively increase weight and reduce water absorption of RCA [9]. Methods listed above were all studied for use of RCA in cement concrete instead of asphalt mixture. Some of them may not be capable for use in asphalt mixture, acid and sodium silicate solution soaking, for example, would result in reduction of cohesion between RCA and asphalt. By pretreating recycled aggregate utilizing a Chinese patented liquid silicone resin [10] provided by Hubei Huanyu Chemical Co. Ltd., Zhu, et al. deceased crushed value of RCA from 27.7% to 25%, and water absorption from 6.76% to 0.97% [11].

2.2. Asphalt mixture containing RCA

As transportation and processing cost of construction waste increase, application of construction waste, especially waste cement concrete, bricks and glass, in asphalt pavement was increasingly valued by researchers in the recent years.

Julian et al. [12] partially substituted RCA for natural aggregate and tested its pavement performance. The result indicated that 75% of natural aggregate could be replaced with RCA when traffic volume was relatively small. Tensile strength ratio, elasticity modulus and dynamic modulus decreased with rising of RCA content. Comparing to asphalt mixture of natural aggregate, asphalt mixture containing RCA was easier to be compacted, saving energy during construction stage. Paranavithana et al. [13] mixed asphalt mixture with coarse recycled concrete aggregate (55%) and natural fine aggregate. All performance indexes of the mixture satisfied the requirements of specification. Bulk density, voids in the mineral aggregate, voids filled with asphalt, elasticity modulus and asphalt film thickness of the mixture were all less than asphalt mixture of natural aggregate, while its volume of voids was larger than asphalt mixture of natural aggregate. Performance of asphalt mixture mixed with natural aggregate and fine recycled concrete aggregate was studied by Wong et al. [14]. it is validated that its performance satisfied Singapore's Marshall test specification, even it behaved better than the asphalt mixture of natural aggregate. Shen et al. [15,16] prepared asphalt mixture with natural aggregate and RCA and found it had better permanent deformation resistance than the mixture only contained natural aggregate. Aljassar [17] studied asphalt mixture prepared by RCA and found its performance in terms of volume, residual Marshall stability and rutting resistance well satisfied the related technique requirements of Kuwait. Asphalt mixture containing coarse recycled concrete aggregate was studied by Perez et al. in Spain [18] and the results indicated that it satisfied the requirement of technique specification for low-class highway pavement, and had good permanent deformation resistance. But it was found to have poor durability due to water sensitivity of RCA. Hu Liqun prepared cement stabilized base course by substituting waste clay brick for natural aggregate at different proportion, a substitution proportion of no more than 70% and 90% was suggested for the use of coarse and fine waste brick aggregate in the mixture [19]. Zhu substituted RCA of Wenchuan earthquake for limestone in asphalt mixture AC-25 at different proportion. It is found that requirements of high and low temperature performance, and water stability in specification were satisfied [11]. Zhang tested pavement performance of AC-25 containing different proportion of RCA and found its high and low temperature performance and water stability were reduced [20]. Gul et al. tested the resistance of asphalt mixtures using RCA by repeated creep tests. It is found that the permanent deformation resistance of the coarse mixtures while increasing the RCA content, but leading opposite effect on the fine graded mixtures [21]. Arulrajah proved that the field performance of a pavement subbase constructed with untreated 100% RAP had insufficient strength requirements to meet local road-authority pavement-subbase requirements [22].