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Effect of temperature on deformation properties of unbound granular materials containing fine RAP

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HIGHLIGHTS

- The rutting potential of UGMs can be lowered to some extent by using fine RAP.
- The rutting potential of the UGMs with or without RAP is temperature dependent.
- The addition of fine RAP has small effect on the stable resilient strain of UGMs.
- The stable resilient strain of UGMs is almost not impacted by temperature.

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ABSTRACT

The impact of temperature on the deformation properties of the unbound granular materials (UGMs) blended with reclaimed asphalt pavement (RAP) and virgin aggregates was investigated based on the single-stage repeated load triaxial (RLT) tests. Three types of the UGMs containing RAP (RAP-UGMs) as well as the UGMs of neat virgin aggregates (VA-UGMs) were tested at the temperatures of 40 °C, 22 °C, and 5 °C. Then, the permanent strain and resilient strain of the UGMs with and without RAP at different temperatures were fitted using the Tseng-Lytton model and a model proposed in this paper respectively. It was found that the rutting potential of UGMs can be lowered to some extent by using fine RAP in an appropriate amount which could be attributed to the enhancement of cohesion due to the presence of asphalt in the fine particles. Generally, the addition of fine RAP has small effect on the stable resilient strain of UGM. The rutting potential of both RAP-UGMs and VA-UGMs is significantly sensitive to temperature. To some extent, that of the VA-UGMs is slightly more sensitive than that of the UGMs containing fine RAP. However, the stable resilient strain of all the UGMs is almost not impacted by temperature.

1. Introduction

The supply shortage and rising costs of virgin aggregates have promoted the usage of recycled and alternative materials from various sources. Using recycled materials such as reclaimed asphalt pavement (RAP) and recycled concrete aggregate (RCA) in road construction has already become a promising engineering solution. Generally, it is considered as a high value-added way to use RAP in hot or warm mix asphalt. However, not all RAP can be used in that way [29]. The statistics on 19 European countries [6] show only 61.06% of the available RAP was used in hot or warm mix asphalt in 2015. A huge amount of RAP is used in another applications or stockpiled. Using RAP in unbounded base or subbase is an important way to alleviate the issue of stockpile. According to the EAPA's statistics [6], the 10% of the available RAP is used in unbound layers for Germany in 2015, 20% for Italy, 61% for Norway, and 98% for Turkey.

Generally, unbound granular layers are susceptible to rutting. The permanent deformation resistance of unbound granular materials (UGMs) is a major concern in practice. Many researchers focus on the deformation properties of UGMs. The deformation properties of UGMs are significantly related to the cyclic load number, which is usually characterized by the repeated load triaxial (RLT) test or accelerated pavement test [7,23,9,10]. Some factors including aggregate angularity, gradation, stress sate, moisture content, freeze-thaw cycle and density are considered to have effects on the deformation properties of UGMs [28,20,24,22,19]. Several

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models were also proposed for predicting the permanent deformation in materials evaluation and pavement structure design [26,17,12,8,13].

It is usually considered that the replacement of virgin aggregates by RAP could to some extent impact the performance of UGMs. Some researchers had investigated the deformation properties of the UGMs containing RAP. According to the results of large-scale model experiments, Kootstra et al. [11] concluded that a greater rutting depth is anticipated when replacing the conventional base course by recycled pavement material and recycled road surface gravel in flexible pavements. Bilodeau et al. [3] quantified the effect of RAP content on the rutting sensitivity of base granular materials using a multistage RLT test. Then, a mechanistic based design procedure was proposed to ensure the base layers containing RAP have a similar rutting behaviour to those made of virgin aggregates. Arulrajah et al. [2] found that the blends of RAP and RCA (recycled concrete aggregate) with a RAP content <15% can meet the requirements of subbase layers. However, the pavement with a subbase constructed totally by RAP has insufficient strength and couldn't meet the local requirements. Stolle et al. [23] investigated the effects of RAP addition on the mechanical properties of granular base using the triaxial tests. It was found that the addition of RAP tends to increase the accumulated permanent deformation. Thakur et al. [25] pointed out that the permanent deformation of the aggregate base containing RAP increases with the increased RAP content. Moreover, the rate of permanent deformation decreases with the increased number of load cycles. Kazmee et al. [10] evaluated the RAP materials for pavement unbound granular layers using an accelerated pavement test. In that study, the base/subbase layers consisting of 100% RAP had higher rutting depths compared to their virgin aggregate counterparts.

Temperature is expected to be a critical factor impacting the deformation properties of the UGMs containing RAP for the presence of asphalt. However, very few research has conducted to evaluate the potential effects of temperature. Wen et al. [27] investigated the effects of temperature on the resilient modulus of the UGMs with different RAP contents and proposed some models to account for the temperature effects. Dong and Huang [5] observed that the creep behavior of the unbound RAP decreased as temperature dropped from 25 °C to 5 °C and the RAP accumulated a larger permanent deformation than the limestone and gravel. Soleimanbeigi et al. [21] found that the average plastic strain of the unbound RAP increased by 0.08% with 1 °C temperature rise. The temperature effects on the deformation properties of the UGMs with RAP are not understood so well by now.

This paper concerns the deformation properties of the UGMs containing fine RAP (hereinafter denoted as RAP-UGMs), as well as the effects of temperature. A series of single-stage repeated load triaxial (RLT) tests were performed on the specimens fabricated with the gap graded, continuous graded and coarse graded RAP-UGMs as well as the UGMs of neat virgin aggregates (hereinafter denoted as VA-UGMs) at 3 temperatures of 40 °C, 22 °C, and 5 °C. The accumulated permanent strain and resilient strain were fitted by the Tseng-Lytton model [26] and a proposed model respectively in accordance with the RLT test results. Then, the temperature effects on the permanent deformation and resilient deformation of the UGMs were investigated. The observations and conclusions could be helpful to improve the usage of RAP in unbound pavement layers.

2. Materials and experiments

2.1. Materials

In this paper, two types of fine RAP, named RAP-1 and RAP-2, were incorporated into UGMs to investigate the deformation properties of the RAP-UGMs through comparison to the VA-UGMs. The grain-size distribution of RAP-1 and RAP-2 is presented in Table 1. The RAP-UGMs and the VA-UGMs were designed in accordance with three gradation types, gap graded, continuous graded and coarse graded, which are suggested by the "Specifications for Design of Highway Asphalt Pavement (JTG D50-2006)" of China [15]. The same limestone aggregates were used in the VA-UGMs and the RAP-UGMs. Meanwhile, RAP-1 and RAP-2 were blended with virgin aggregates in different ratios for various gradation types to ensure each RAP-UGM has an almost same gradation as the corresponding VA-UGM. Fig. 1 depicts the grain-size distribution of each UGM. Table 2 presents the content of RAP-1 and RAP-2 in each gradation, as well as the total asphalt content of each RAP-UGM. More detailed descriptions about the test materials could be found in somewhere else [14].

2.2. Specimen preparation

The optimum moisture and the maximum dry density of each UGM, presented in Table 3, were determined using the heavy rammer compaction test (T0131-2007) of the "Tests Methods of Soils for Highway Engineering (JTG E40-2007)" of China [16]. A specimen size of 150 mm diameter by 150 mm height was used in this paper, which was employed in many other research for characterizing the permanent deformation of UGMs with the RLT test [8]. The optimum moisture content and the compaction degree of 100% are adopted for fabricating specimen in this study. The specimen preparation procedure as well as other related information

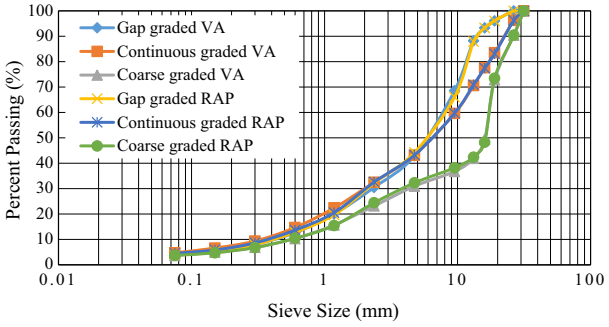

Fig. 1. Grain-size distribution of the UGMs.

Table 2
RAP and the total asphalt contents of the RAP-UGMs.

Gradation type	RAP-1	RAP-2	Asphalt content
Gap graded	15%	20%	2.183%
Continuous graded	0%	15%	1.041%
Coarse graded	5%	13%	1.167%

Table 1
Grain-size distribution of RAP-1 and RAP-2.

Sieve size (mm)	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
RAP-1	100	95.02	0	0	0	0	0	0	0
RAP-2	100	100	100	39.99	14.12	5.5	1.46	0.93	0.66