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A novel double-drum mixing technique for plant hot mix asphalt recycling with high reclaimed asphalt pavement content and rejuvenator

Huijun Shao [a], Lijun Sun [a], Liping Liu [a,*], Zhanping You [b], Xu Yang [b]

[a] The Key Laboratory of Road and Traffic Engineering, Ministry of Education, Tongji University, Shanghai 201804, China
[b] Department of Civil and Environmental Engineering, Michigan Technological University, MI 49931, United States

HIGHLIGHTS

- A novel double-drum mixing technique is proposed and evaluated.
- This mixing technique can reduce the air voids of hot recycled asphalt mixtures.
- This mixing technique can improve the performance of hot recycled asphalt mixtures.

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ABSTRACT

Hot mix asphalt (HMA) recycling has been widely used in pavement engineering. When the content of reclaimed asphalt pavement (RAP) is high, asphalt rejuvenator is often used to improve the performance of asphalt mixtures. The existing mixing technique of HMA recycling with rejuvenator is adopted from the traditional hot mix asphalt plant with one mixing drum. The drawbacks of this mixing technique are that the rejuvenator cannot fully interact with RAP and some aggregates may not be well coated with virgin asphalt binder. In recognition of these, a novel mixing technique, namely double-drum mixing, is proposed and evaluated. A comparative study was carried out to investigate the effect of double-drum mixing on the performance of hot recycled asphalt mixtures. In detail, the volumetric properties, tensile strength, moisture damage resistance, rutting resistance, and low temperature cracking resistance were evaluated. Two asphalt mixtures (AC-13 and AC-25) with three RAP contents (40%, 50% and 60%) were investigated. The results showed that the proposed new mixing technique can improve the performance of hot recycled asphalt mixtures in several aspects. The double-drum mixing process can reduce the air voids if all other mix design parameters are the same. Additionally, the tensile strength, moisture damage resistance, rutting resistance, and low temperature cracking resistance were improved to a certain extent.

1. Introduction

Reclaimed asphalt pavement (RAP) has been very popular in the pavement industry due to its remarkable benefits such as saving landfill space, reducing environmental pollution, and cost effectiveness [1–3]. It has been reported that the use of RAP can cut the cost of hot mix asphalt (HMA) pavement by as high as 50% [4]. Technologies of asphalt pavement recycling mainly include central plant cold recycling, cold in-place recycling, central plant hot recycling and hot in-place recycling. Warm mix asphalt containing RAP has also attracted interests for the purpose of energy savings and emission reductions [5–7]. Among these technologies, the central plant hot recycling is by far the most widely used and the most promising technology in highway engineering. HMA containing RAP can be used as both the surface and base layers [8]. A large amount of lab studies and field construction have shown that HMA mixtures with RAP can meet normal specification requirements, as long as they are properly designed and constructed [9–13]. The design of HMA containing RAP assumes that the mixtures are produced using a process that results in complete mixing of RAP with virgin asphalt binder, rejuvenator and aggregates. To improve the performance of HMA containing RAP, an important consideration is ensuring adequate mixing of the RAP and new adding materials. Inadequate mixing will greatly reduce the degree of adhesion between RAP and the new adding materials and cause pavement distresses such as raveling and cracking. Especially, the degree of mixing will reduce with the increase in RAP content.

* Corresponding author.
E-mail address: llp@tongji.edu.cn (L. Liu).

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Therefore, many agencies stated high limits of RAP in asphalt mixtures, especially for the pavement with high traffic and severe weather conditions [14]. Nevertheless, the attempt of using high RAP content has never stopped in research around the world.

Previous studies have shown that the performance of aged RAP asphalt binder can be improved during the blending process with virgin asphalt binder [15–17]. This phenomenon is called rejuvenation of the RAP asphalt binder. Rejuvenation can be defined as 'the recovery of their original performances'. Therefore, the rejuvenation of RAP asphalt binder is the key in recycling technology, which means the performance of RAP asphalt binder needs to meet the requirements of pavement. Compared with RAP asphalt binder being rejuvenated by virgin asphalt binder, researchers have been making efforts to produce a rejuvenator that can be added into the RAP to adjust the mutual proportions of the RAP asphalt binder components to regain its balance [18]. When blending virgin asphalt binder or rejuvenator with RAP asphalt binder, the property of the RAP asphalt binder will be improved, known as rejuvenation. The rejuvenation process of RAP asphalt binder has been well verified by researchers [19–22]. A better rejuvenation of RAP asphalt binder can lead to a better degree of mixing between RAP and new adding materials, therefore, a better performance of the HMA containing RAP will be obtained. The quality of the rejuvenation of RAP asphalt binder can be affected by many factors, such as the type of virgin asphalt binder, type of rejuvenator, and the mixing process [23]. The central plant mixing process of HMA containing RAP has been well developed in the last decades. A widely used single-drum mixing technique is to first mix virgin aggregates and RAP. Then the mixed particles, virgin asphalt binder and fillers are fed into the drum for final mixing. When the content of RAP is more than 30%, rejuvenator is sometimes recommended to improve the performance of asphalt mixtures [24,25]. When rejuvenator is included, the current practice of single-drum mixing is to make a slight modification of the non-rejuvenator process by feeding it into the drum with the virgin asphalt binder. An obvious concern of this widely used process is that the rejuvenator is mainly developed to act on the RAP asphalt binder, so if it is fed with virgin asphalt binder and then sprayed on both the virgin aggregates and RAP, its interaction with RAP is actually not fully utilized. This would increase the dosage of rejuvenator. Another more serious problem is that some aggregates may not be well coated with virgin asphalt binder, even though the optimum asphalt binder content is adopted. Thus, this study aims to modify the existing plant mixing process to improve the performance of HMA containing RAP.

2. Objective

The objective of this study is to propose a new mixing technology, namely the double-drum mixing technique, for HMA with high RAP content and rejuvenator and to evaluate the viability of such a mixing technique. To achieve the objective, several laboratory experiments were conducted to evaluate the effect of the double-drum mixing process on the volumetric properties, tensile strength, moisture damage resistance, rutting resistance and low temperature cracking resistance of HMA containing RAP.

3. The double-drum mixing technique

A conventional intermittent or continuous plant mixing for new HMA can also be employed for HMA containing RAP by adding an independent RAP feeder. The schematic setup of this mixing process is shown in Fig. 1.

In the existing plant mixing process for HMA containing RAP, RAP and virgin aggregates are first mixed for 90 s, as seen by the 'Step 1' in Fig. 1. The virgin aggregates are preheated at a temperature above 180 °C before the mixing. The RAP needs to be preheated as well when the RAP content is high. The recommended preheating temperature for RAP is no higher than 110 °C to avoid over aging [26]. Rejuvenator is used when RAP content is high in many practical projects. The current practice of adding rejuvenator is to feed rejuvenator with virgin asphalt binder, and then to be mixed for another 90 s, as seen by 'Step 2' in Fig. 1. It should be noticed here that the mix of virgin aggregates and RAP was already in the drum before the rejuvenator and virgin asphalt binder were added. Finally, the fillers are fed into the drum for a final mixing of 90 s, as seen by 'Step 3' in Fig. 1. While this mixing process is simple and easy to employ in the existing mixing plants, there are obvious drawbacks. First, the purpose of adding a rejuvenator is to rejuvenate the RAP asphalt binder, so it is desirable that the rejuvenator can fully interact with RAP. In the existing mixing process, since the rejuvenator is fed with virgin asphalt binder, it interacts with both the virgin aggregates and the RAP. In this case, only part of the rejuvenator interacts well with RAP. In this case, the rejuvenator is under-utilized. As a result, more rejuvenator needs to be added to achieve equivalent rejuvenation outcomes.

Second, because RAP particles and virgin aggregates have different surface areas (SA), the coat-ability of asphalt binder may be affected. For example, different surface areas of RAP particles and virgin aggregates that were used to design HMA mixtures containing RAP were calculated as in formula (1):

$$SA = \Sigma P_i \times FA_i \tag{1}$$

where: SA is the surface area, m^2/kg; P_i indicates the percent passing at each size of aggregate, %; FA_i is the surface area ratio of each aggregate size, shown in Table 1; Note: when the size of aggregate is larger than 4.75 mm, FA_i is 0.0041, and it can be calculated just one time.

The results are shown in Table 1, which clearly indicates that the surface area of RAP particles is greater than that of virgin aggregates, mainly because the fine particles in the RAP made up a large proportion of the final mixtures. Therefore, the RAP particles will attract much more asphalt binder than the virgin aggregates. This may result in the insufficient wrap of virgin aggregates.

In recognition of the drawbacks of the conventional mixing process, a novel mixing process is proposed in this study, named the double-drum mixing process. The schematic setup of the double-drum mixing is shown in Fig. 2.

In the beginning, the total virgin asphalt binder was divided into two equal portions. One half of the total virgin asphalt binder was mixed with virgin aggregates for 90 s in the first drum, as shown by 'Step 1' in Fig. 2. Meanwhile, different from the conventional process of mixing the RAP and virgin aggregates first, the new mixing process allows the rejuvenator and the RAP to be mixed first so that the RAP can fully interact with the rejuvenator before it is mixed with virgin asphalt binder and virgin aggregates. This mixing step took place in the second drum for 90 s, as shown by 'Step 1' in Fig. 2. The mixing processes occurring in the two drums were conducted at the same time to reduce the total mixing period. Then the products in the first drum, and the other half of the total virgin asphalt binder, were fed into the second drum and mixed for another 90 s. It should be noticed here that the mixing of RAP and rejuvenator is already in the second drum. Afterward, fillers were fed into the second drum and mixed for another 90 s. Here, the final product of the HMA containing RAP is produced. Because this mixing process needs two mixing drums, it is called double-drum mixing in this study. So far, this double-drum mixing plant has been manufactured and served several projects in Shanghai, China. While the benefits of the double-drum mixing technique are perceptible, the potential negative aspects