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Effects of production stages on blending and mechanical properties of asphalt mixtures with reclaimed asphalt pavement

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HIGHLIGHTS

- RAP mixtures that underwent different production stages were produced.
- Diffusion is the most dominant stage that affects properties of RAP mixtures.
- Thorough mechanical blending improves the ductility of RAP mixtures.

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ABSTRACT

This study is to investigate the effects of production stages, including RAP binder transfer, mechanical blending, and diffusion, on the blending of RAP and virgin binders and the mechanical properties of RAP mixtures. A laboratory mixing scheme was designed to produce 26 and 50 percent RAP mixtures that underwent a combination of the different production stages. The results show that diffusion is the most dominant stage that affects the rheological and fracture properties of RAP mixtures. On the other hand, thorough mechanical blending contributes to improving the ductility of high percentage RAP mixtures.

1. Introduction

Reclaimed asphalt pavement (RAP) is increasingly being used in asphalt mixtures as a substitute of virgin binder and virgin aggregate. In the United States, the estimated savings by using RAP in the pavement construction were near $2.04 billion in terms of conserved asphalt binder in the year of 2012 [1]. However, only 12 percent RAP was incorporated in asphalt mixtures on average, and over half of the state transportation departments used less than 20 percent RAP [2]. One of the reasons that has prevented the use of high percentages of RAP (more than 25 percent) is that the aged RAP binder could increase the stiffness or brittleness of RAP mixtures and result in less resistance to fatigue or thermal cracking in pavements [3–8]. In order to alleviate the stiffening effect of RAP binder on high percentage RAP mixtures, softer virgin binder is used in the mix design stage [9,10]. The performance of RAP mixtures in these cases could, however, be affected by the degree of blending between stiff RAP binder and soft virgin binder used in high percentage RAP mixtures [11]. Research has been conducted to determine the degree of blending that takes places between recycled binders in RAP or reclaimed asphalt shingles and virgin binders [11–17]. However, the effects of the production stages of RAP mixtures, illustrated in Fig. 1, on their blending and mechanical properties remain unclear, especially for high percentage RAP mixtures. It is noted that a few studies have investigated the influence of plant type and production parameters on the performance of RAP mixtures [18].

Fig. 1 schematically shows the production stages that could affect blending between RAP and virgin binders. The first stage that is referred to as the 'RAP binder transfer' in this study occurs during the dry mixing and heating of the RAP materials by the superheated virgin aggregate, during which the RAP binder is mobilized and transferred onto the virgin aggregate that have been identified from the laboratory experiments and field batch plant case [20–23]. At the second production stage, a virgin binder is sprayed into the mixing chamber or pugmill and blended with RAP binder by mechanical mixing paddles. In this study, this stage is referred to as the 'mechanical blending' stage and it facilitates the blended binder transfer in RAP mixtures. The third stage referred to as 'diffusion' stage here occurs from the discharge of RAP mixtures from

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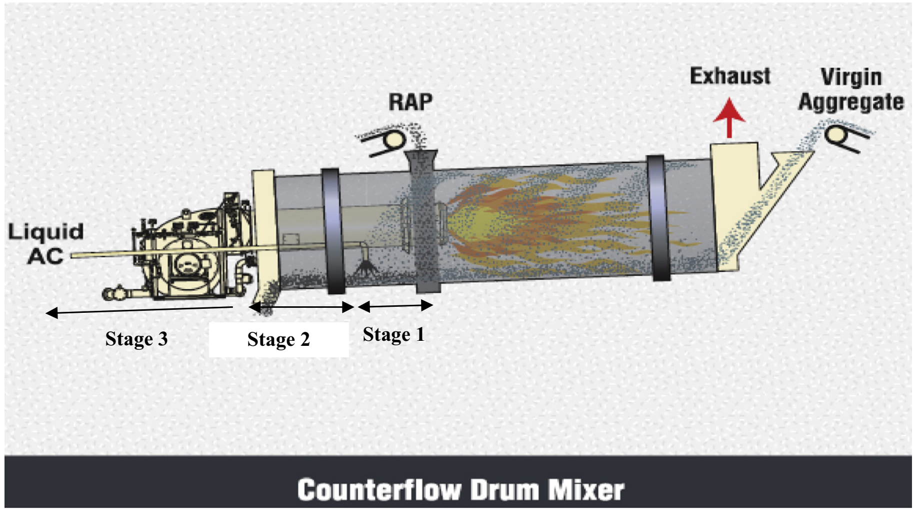

Fig. 1. Schematic illustration of production stages of RAP mixtures [19].

the drum plant or pugmill and continues through their storage in the silo, transportation to the field site, paving and compaction, and throughout the entire life of the pavement.

In a previous study by our group, we have proposed a mixing scheme to produce RAP mixtures that experienced different production stages and investigated the effects of production stages on the rheological and fracture performance of asphalt mixtures with the 26 percent RAP [24]. The results of the 26 percent RAP mixtures indicated that the diffusion is the most dominant stage that affects blending and mechanical properties of the RAP mixtures. However, this conclusion is needed to be validated by other sources of RAP materials and the asphalt mixtures with a higher RAP percent, e.g. 50 percent. Thus, the objectives of this study are to validate whether diffusion is the dominant mechanism for asphalt mixtures with other RAP sources at the RAP binder replacement ratio of 26 percent, and examine the primary mechanism that underlies the blending of the RAP and virgin binders for the asphalt mixtures with 50 percent RAP. Moreover, the different fracture mechanisms of RAP mixtures at 20 °C and −10 °C are discussed in this paper.

2. Materials and experiments

2.1. RAP characterization

The RAP used in this study was obtained from local Poe Asphalt Paving, Inc. plant in Pullman, WA. The RAP has an asphalt content of 4.4 percent; the bulk specific gravity of RAP aggregate is 2.777; and the true performance grade (PG) of the RAP binder was determined to be PG 83.8-18.3 based on the critical high and low temperatures of the recovered RAP binder using AASHTO M323 [9].

2.2. Mix designs

The total optimum binder content for the mixtures with 26 percent RAP was determined using the Superpave mix design method. Table 1 presents the total optimum binder content, final blended gradation, volumetric properties, and specification requirements. In this study, because the control mixtures and the 50 percent RAP mixtures were designed to have the same aggregate gradation as the 26 percent RAP mixtures, the total optimal binder contents for the control mixtures and the 50 percent RAP mixtures were controlled to be the same as that for the 26 percent RAP mixtures. The targeted PG of asphalt binder used in the mixtures in Pullman area is PG 64-28. For the 26 percent RAP mixtures, the virgin binder grade is needed to be adjusted one grade lower at PG 58-34, when compared with the targeted PG of asphalt binder. The virgin binder grade used for the 50 percent RAP mixtures was adjusted at PG 52-34, based on the blending chart [3] and local availability.

2.3. Mixing scheme design

The mixing schemes for the RAP mixtures were carefully designed to distinguish the three production stages in the different RAP mixtures. Fig. 2 presents a flow chart of the mixing schemes developed for the four different RAP mixtures, Mixes A, B, C, and D, and two control mixtures without RAP as the Mixes E and F. Table 2 summarizes the experienced production stages and PG of virgin binder used in the each mixture.

As illustrated in Fig. 2, prior to mixing, the virgin aggregate, virgin binder, and RAP were heated separately to the mixing temperature. For Mix A, the virgin aggregate and virgin binder were mixed first at the mixing temperature in a laboratory drum mixer to produce a mix that would not include the RAP binder transfer onto the virgin aggregate. Both the virgin mix and RAP were cooled to the ambient temperature and then reheated separately at the compaction temperature for 2.5 h. It is noted that this cooling process was designed for all six mixtures to remove the confounding effect of aging of the virgin binder during reheating. Fifteen minutes prior to compaction, the virgin mix and RAP were mixed manually, but lightly, in a pan using a spatula instead of by a powered mixer. This process was intended to minimize particle collisions and other forces to minimize the effect of mechanical

Table 1
Mix design results for RAP mixtures.

POE RAP Mixes	Sieve Size (mm)										Specification
	19.0	12.5	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075	
Percent Passing, %	100	93	79	50	33	24	17	13	8	4.8	NA
Total Optimum Binder Content, %	5.1										NA
Air Voids, %	4.0										4.0
VMA, %	14.2										14 min
VFA, %	72										65–75
Dust-to-Asphalt Ratio	1.1										0.6–1.6
Target PG of Binder	64–28										NA