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The use of CRM-modified asphalt mixtures in Korea: Evaluation of high and ambient temperature performance

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HIGHLIGHTS

- CRM-modified asphalt mixes were prepared by dry and wet process using CRM contents of 8%, 10% and 12%.
- The fatigue life was improved most significantly by CRM modification, compared with SD and ITS.
- The moisture resistance of CRM mix was found to be very poor after freezing and thawing treatment.
- The hydrated lime (HL) was highly effective in improving the concerned performance of CRM mixes.

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ABSTRACT

The asphalt mixtures modified with crumb rubber modifier (CRM) were evaluated to estimate the deformation resistance at a high service temperature, fatigue resistance and tensile strength at ambient temperatures. As a mean to address the early-life failures of the mixtures observed from a number of pavements in Korea, the study also investigated the moisture susceptibility after freezing-and-thawing (F/T) treatment by indirect tensile strength (ITS) test. A series of CRM-modified asphalt mixtures (CRM mixtures) were prepared by dry process as well as wet process using the CRM contents of 8%, 10% and 12% by weight of total binder, respectively. The test results showed that fatigue resistances of CRM mixtures were significantly improved, compared with the normal mixture (control) without CRM, but the moisture resistance after F/T treatment was found to be very poor. The poor performance of the CRM mixtures in terms of moisture sensitivity appears to explain the early-life failures experienced in Korea. The study then examined the effectiveness of hydrated lime (HL) in improving the concerned performance since the HL is a well-known moisture resistance additive for conventional asphalt mixtures. The test results showed that CRM-mixtures containing the HL had marked improvement in moisture sensitivity.

1. Introduction

The ground waste tire rubber, or crumb rubber modifier (CRM), is widely used as an asphalt modifying material in asphalt pavement in the world [1–5,11,24]. In Korea, CRMs have been increasingly used as an asphalt modifier in paving industry [6–8,12,20]. However, because of poor adsorption of asphalt binders to granite-base aggregates which are relatively abundant in Korea, a significant portion of the CRM-modified asphalt mixtures (CRM mixtures) placed in pavements in Korea were disintegrated in earlier age after experiencing a freezing winter. In the following spring season, significant stripping in the mixture and raveling in the surfacing layers were often noted. The reason was thought to be due to the distress caused by freezing and thawing of water infiltrated through cracks on the pavement surface. Following thawing in spring time and rainy spells during the summer, many potholes were observed at the sites where cracks were visible from the surface. Those distresses are thought to be due to the stripping of mixtures in ambient or relatively low temperatures [7,8].

It is interesting to note that those problematic CRM mixtures were typically found to be satisfactory when performance against rutting at high service temperature was assessed. This suggests that the uncertainty in cracking-related performances of CRM mixture at ambient/low temperatures would be the main risk of using the material. Therefore, ongoing efforts should be made to establish mitigation/ prevention practices so that the risk can effectively be accounted for.

This study supplements previous studies that investigated cracking-related property at ambient-temperature and rut-related

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Fig. 1. CRM powder passing #30 mesh.

property at high-temperature [5,7,12,13]. Several treating agents were used for improving properties of the CRM mixtures [1,6]. From those studies, it was observed that the hydrated lime (HL) would be the best choice as an anti-stripping additive for normal asphalt concrete. However, few studies dealing with CRM mixtures were conducted in depth in Korea where humid-and-hot summer and freezing winter are expected. Therefore, the HL was used as an anti-stripping additive for CRM mixture in this study. The objective of this study was to evaluate the fatigue resistance as a cracking-related property at ambient-temperature and the deformation strength (S_D) as a rut-related property at high-temperature [9,15,18] with particular emphasis given to moisture susceptibility of CRM mixtures.

2. Materials and methods

A source of a PG 64-22 asphalt binder (AP5), which is most widely used in South Korea was used as a base binder in this study. A size of minus 30 mesh of CRM, produced by the mechanical shredding in ambient temperature, was prepared for this study as shown in Fig. 1. The CRM contents were 8%, 10% and 12% by weight of total binder. Granite coarse and fine aggregates were used for 13 mm dense-graded surface course, as shown in Fig. 2. Limestone powder was used as mineral filler. As an anti-stripping additive, the hydrated lime (HL) was used. Table 1 shows physical properties of aggregate and filler materials together with the specification limits given by the Ministry of Land, Infrastructure and Transport, South Korea.

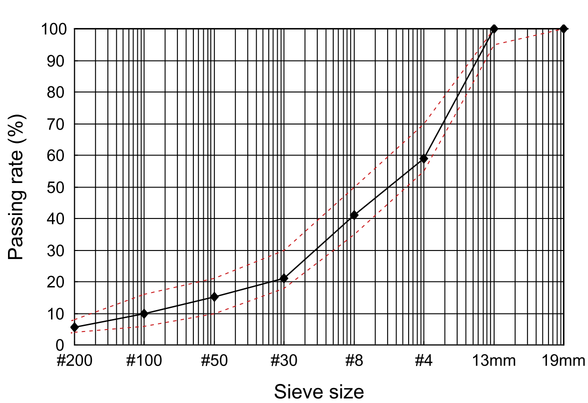

Fig. 2. Gradation of combined aggregates.

Table 1
Physical properties of materials.

Property	Specification	13 mm agg.	Fine agg. (screenings)	Filler
Apparent specific gravity	>2.45	2.686	2.696	2.75
Absorption (%)	<3.0%	1.143	1.297	
Abrasion (%)	<35%	22.44		

2.1. Preparation of sample

For wet process, the rubber-modified binder was prepared by slowly adding the CRM into the binder while mixing at 5000 rpm with a homogenizer at 180 °C for 30 min. The reaction time of 30 min were selected based on previous study results [3,5,13]. For dry process, the CRM was directly added into asphalt mixture while the heated binder and aggregates were blended in the mixer.

The optimum binder content (OBC) was determined based on 4% air void for each CRM mixture by mix design using 100 mm diameter specimens compacted using a Superpave gyratory compactor (SGC). The 75 and 100 gyrations were applied for compaction of the normal mixtures and CRM modified mixtures, respectively. The specimens for moisture susceptibility test were compacted only up to 20 gyrations so that a higher air voids of 7% could be achieved as required by the test method. Since the HL is fine powder (more than 90% passing #200 sieve), the 1/2 of mineral filler was replaced with HL. HL was only added to the specimens prepared for the moisture susceptibility testing.

2.2. Tensile strength ratio

The moisture susceptibility was evaluated by the indirect tensile strength (ITS) test before and after F/T treatment. The vacuum-saturated specimen to the degree of 70–80% was covered with a plastic film and each wrapped specimen was sealed in a plastic bag containing 10 g of water. The plastic bag containing each specimen was placed in a freezer at a temperature of −18 °C for 16 h. The frozen specimen bag was submerged in a water container at 60 °C, and the plastic bag and wrap were removed from the specimen as soon as it was submerged into the water. After 24 h in the 60 °C water bath, the specimen was removed and placed in a water bath at 25 °C for 2 h according to the guideline of ASHTO T283-07 [27]. The specimen was removed from the water bath, and ITS was measured by applying 50 mm/min static loading through the steel loading strips at 25 °C.

The retained tensile strength ratio (TSR) was calculated from the test results before and after conditioning by the equation below.

$$\mathrm{TSR}\ (\%) = \frac{\mathrm{ITS_w}}{\mathrm{ITS_D}} \times 100 \tag{1}$$

where $\mathrm{ITS_W}$ is ITS after F/T treatment and $\mathrm{ITS_D}$ is ITS without F/T treatment.

2.3. Deformation strength

The deformation strength (S_D] is a measure of resistance against deformation induced by a static-mode loading applied on top of a briquette specimen of asphalt mixture at a high temperature [15]. The test procedure, designated as "Kim Test," uses the specimen (100 or 150 mm diameter) heated in 60 °C water for 30 min before placing in the specimen holder, as shown in Fig. 3(a). A static loading at the speed of 30 mm/min is applied through the loading head, a steel rod, with a 40 mm diameter and 10 mm radius of round cut at the bottom edge. Since the S_D was found to have a good correlation with rut characteristics of dense grade HMA mixtures when correlate to the conventional wheel tracking test [9,15,17,18,22], it was adopted as a standard criterion in Korean mix-design guide [26]. The peak load, P_{max}, and vertical deformation, v, at P_{max}, were read from the curve (Fig. 3(b)) and used for S_D calculation using Eq. (2).

$$S_D = \frac{0.32 P_{max}}{\left(10 + \sqrt{20v - v^2}\right)^2} \tag{2}$$

where S_D = deformation strength (MPa), P_{max} = peak load (N), v = vertical deformation (mm) at the P_{max}.

The Korean specification limits for S_D for 100 mm and 150 mm diameter specimens are $S_D \geqslant 3.20$ MPa and 3.60 MPa for the secondary-class road asphalt pavement, and $S_D \geqslant 4.25$ MPa and 4.75 MPa for the arterial road pavement, respectively [26]. The S_D testing was conducted in triplicate. More details of the Kim Test procedures are given elsewhere [9,15,18,23].

2.4. Fatigue resistance

The failure of a specimen due to fatigue loading consisted of 3 stages; 1st or primary stage due to condensation, 2nd stage for steady increase of deformation due to repeated load cycles and 3rd stage reaching failure. The fatigue life or the number

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