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Laboratory performance of warm mix asphalt containing recycled asphalt mixtures

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HIGHLIGHTS

- WMA mixtures containing high percentage of RAP were produced using different WMA additives.
- WMA additives lowered the mixing and compaction temperatures of mixtures.
- Performance evaluation on rutting, low temperature cracking, moisture damage, aging, and fatigue of mixtures.
- Effect of WMA additives and RAP on the performance of mixtures was pronounced.

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ABSTRACT

This study aims to evaluate the laboratory performance of warm mix asphalt containing reclaimed asphalt pavement (WMA–RAP) materials. The WMA mixtures containing 0% and 40% RAP were produced using Evotherm-DAT and S-I WMA additives. The laboratory performance tests included rutting, bending, freeze–thaw splitting, Marshall immersion, aging, freeze–thaw cycles splitting, and fatigue tests. The moisture and low temperature cracking resistance were evaluated for aged mixtures. The results showed the WMA mixtures without RAP performed better moisture and low temperature cracking resistance, and lower rutting resistance than the WMA–RAP mixtures. The WMA mixtures suffered from the short-term aging exhibited a slight increase as compared to the unaged mixtures, whereas the long-term aging resulted in a distinct reduction in terms of the moisture resistance. After the short- and long-term aging, the WMA mixtures exhibited a greater decrease than the unaged mixtures in terms of the low temperature cracking resistance. The tensile strength ratio (TSR) results of the WMA–RAP mixtures generally decreased with the increase of freeze–thaw cycles, while the TSR results showed an obvious increase after three freeze–thaw cycles. The addition of RAP significantly reduced the fatigue resistance of the WMA–RAP mixtures in comparison with the WMA mixtures without RAP. Based upon the study findings, the moisture resistance under freeze–thaw cycles conditioning remains an issue to be considered in the WMA–RAP mixtures.

1. Introduction

Warm mix asphalt (WMA) is a technology that allows producing asphalt mixtures at lower temperature than those in the production of traditional hot mix asphalt (HMA). The production of WMA mixtures requires lowering the manufacturing temperature without reducing their level of mechanical performance. Several advantages of WMA include reduced greenhouse gas emissions, better working conditions, lower energy consumption, longer hauling distances, etc. Currently, WMA can be produced by the addition of organic additives and chemical additives or through the foaming technologies (water-bearing additives or water-based processes) with the objective to increase the mixture workability at reduced temperatures [1]. The application of organic additives lowers production temperature by decreasing the asphalt binder viscosity, while the chemical additives reduce the internal friction between aggregate particles without change of binder viscosity [2,3]. The foaming technologies are based on the injection of small amounts of water along with the liquid asphalt binder during the mixing process which in-turn causes the asphalt binder to expand

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in volume and foam at a given temperature. The foaming process helps the liquid coat the aggregate at reduced temperatures [4].

Asphalt pavement in need of reconstruction or new overlay is a candidate for recycling. Over the years, a lot of recycling technologies have been developed for reclaimed asphalt pavement (RAP), and each of the technologies is specialized to dispose a given task. The central plant hot recycling technology is widely used due to many benefits including proper mixture gradation controlling, stable quality, reliable performance, etc. Moreover, the performance of hot recycled asphalt mixture (HRAM) can be restored to the equivalent level of HMA, and thus the central plant hot recycling technology is particularly applicable in recycling of the overused asphalt pavement [5]. However, in the production of HRAM, which cannot be heated by the open flame, it is difficult for RAP to obtain the desired mixing temperature. The higher mixing temperature of HRAM tends to make the reclaimed asphalt engender secondary aging, which may be a bottleneck in the service of the central plant hot recycling technology. The smaller RAP content to control the production quality of HRAM is also the technology disadvantage in comparison with the higher RAP content in the cold recycling technology. The combination of the WMA technology with the central plant hot recycling technology can be useful to significantly reduce the mixing and production temperatures of warm mix asphalt containing reclaimed asphalt pavement (WMA–RAP) mixtures. The reduction in temperatures means less energy cost in production, and the decrease in fuel consumption will lower fumes and greenhouse gas emissions. This may also be beneficial to the mixing of virgin asphalt and aged asphalt at lower temperatures, the high RAP content, and furthermore, the production quality and workability of reclaimed asphalt mixtures.

In recent years, the research and practical use of WMA–RAP mixtures have been increasingly performed by researchers and practitioners. A lot of different WMA additives were employed to obtain WMA binder derived from the mixing of virgin asphalt and RAP [6–8]. Evotherm and Sasobit WMA additives were used to investigate the laboratory performance of WMA–RAP mixtures to seek ways to incorporate as high amount of RAP as possible. Compaction characteristics of the Sasobit WMA containing RAP ranged from 0% to 60% was evaluated using different compaction temperatures [9]. Marshall immersion and freeze–thaw splitting tests were conducted to evaluate the moisture susceptibility of WMA–RAP mixtures produced using the Evotherm, at RAP contents of 0%, 30%, 40%, and 50% [10]. The skid resistance testing was performed using a dynamic friction tester in conjunction with a circular texture meter to evaluate the skid resistance of the Evotherm WMA mixtures containing 0%, 50%, and 100% RAP [11]. Laboratory tests including rutting and freeze–thaw splitting tests were conducted to evaluate the Evotherm WMA mixtures with different RAP contents [12]. The rutting, bending, and freeze–thaw splitting tests were performed for evaluation of the Sasobit WMA mixtures containing RAP content ranged from 0% to 60% [13]. The four-point bending beam fatigue test at a controlled-strain mode was conducted to evaluated the fatigue resistance of WMA–RAP mixture produced using the Evotherm and 45% RAP [14]. Moreover, the WMA containing reclaimed modified asphalt or reclaimed asphalt with recycled asphalt shingle (RAS) were evaluated through laboratory performance tests. Marshall mix design procedure was utilized to design the recycled SMA (Stone Mastic Asphalt) mixture with the Evotherm. Meanwhile, a laboratory study was carried out to investigate the mixing temperature and fatigue properties of the mixture with a rejuvenating agent [15]. The bending beam rheometer (BBR) test and asphalt binder cracking device methods were conducted to evaluate the low temperature performance of the Sasobit WMA binder materials containing RAS, RAP, and bioasphalt [16].

Highway engineers started to use the foaming technologies in WMA–RAP mixtures construction due to cost-effectiveness. In general, the foaming technologies do not require any costly additives to be added to the mixtures. More importantly, the foaming technologies have not very expensive plant modifications requirement since the foaming component can be attached to plant systems for a reasonable price without the need for major changes. In a study, the dynamic modulus and indirect tensile tests of mixtures compacted using a Superpave gyratory compactor were conducted to characterize the mechanical properties of porous asphalt pavement mixtures containing 15% RAP and a water-bearing WMA additive (Advera) [17]. The freeze–thaw tensile strength, Superpave indirect tension, dynamic modulus, and Hamburg wheel tracking tests were conducted to evaluate the moisture susceptibility of plant-produced foamed (water-based) WMA containing up to 50% RAP [18]. Moreover, the stiffness characteristics, moisture susceptibility, rutting, and fatigue resistance of plant-produced foamed (water-based) WMA mixtures with RAP content ranged from 15% to 40% were evaluated using laboratory tests [19,20].

One classification of WMA differentiates those mixtures mentioned above according to the temperature reduction achieved and divides them into two groups: WMA and Half-WMA. A laboratory study was carried out to evaluate the moisture susceptibility, rutting, and fatigue resistance of laboratory-produced Half-WMA mixtures containing moist aggregates, RAS, and RAP [21].

Although previous studies shown above which mainly focused on evaluating WMA–RAP mixtures in terms of moisture susceptibility, rutting and low temperature cracking resistance as measured in the laboratory, the durability concerns such as aging and moisture remain in WMA–RAP technology, and then the long-term performance of the field pavement could not be evaluated. Presently, the WMA additives used mostly in China are produced by the U.S. and some countries in Europe. Although the WMA additives can efficiently reduce fabrication temperatures of WMA–RAP mixtures, higher cost and more complicated addition processes to some WMA additives result in a impediment to practical use of WMA–RAP mixtures to some degree at least. In order to gain more benefits from WMA–RAP technology, WMA additives that are cost-effective, workability-efficient, and appropriate for the appointed region have been developing in China. Additionally, the percentages are selected based upon the Chinese technical specifications (Technical Specifications for Recycling of Highway Asphalt Pavement (JTG F41-2008)), which define and specify the design requirements of HRAM with RAP contents as not more than 30%. Therefore, the laboratory performance of WMA mixtures containing high percentage of RAP should be considered as the main concern of interest covered in this study.

2. Objectives and scope

Based on the reconstruction project of a highway asphalt pavement in Liaoyang China, the selected WMA additives and rejuvenating agent were added into hot recycled asphalt to lower the mixing and compaction temperatures and increase the RAP content. The objective of this study is to evaluate the laboratory performance of WMA mixtures containing 0% and 40% RAP through the rutting, bending, freeze–thaw splitting, Marshall immersion, aging, freeze–thaw cycles splitting, and fatigue tests. The mixing and compaction temperatures of mixtures would significantly affect the compaction characteristics and mechanical properties of the WMA–RAP mixtures. Therefore, the analysis of the compaction characteristics was performed to obtain the fabrication temperatures of the WMA–RAP mixtures. Aging processes have considerable impact on the field performance of the mixtures. The short- and long-term aging tests were used to evaluate the