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Feasibility of Superpave gyratory compaction of rubberized asphalt concrete mixtures containing reclaimed asphalt pavement

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ABSTRACT

Recently, some specific materials such as ground crumb rubber are widely being used to save money (e.g. longer life) and protect the environment. In addition, the utilization of reclaimed asphalt pavement (RAP) is an acceptable practice in many states. However, the use of these materials in the Superpave mix design system is not standardized, so it is essential to investigate whether a rubberized asphalt concrete (RAC) mixture containing RAP can be used in the Superpave mix design procedure. In general, the use of RAP in the past has proven to be economical, environmentally sound, and effective for enhancing the engineering properties of asphalt mixtures. Crumb rubber has also been used successfully in improving the mechanical characteristics of an HMA mixture. The objective of this research was to investigate the feasibility of the Superpave mix design of rubberized asphalt mixtures containing RAP through volumetric analysis of various mixtures with respect to crumb rubber type, percentage and RAP percentage in the mixture. The results of this limited study indicated that increasing the rubber content led to an increase of the optimum binder content; the two rubber types had good workability with virgin and RAP mixtures; and the Superpave mix design method and volumetric analysis can be used for the rubberized asphalt mixtures containing RAP.

1. Introduction

Many states have begun implementing Superpave hot mix asphalt (HMA) mix design system, developed by the Strategic Highway Research Program (SHRP), in mid 1990s. In the Superpave mix design and analysis system, Superpave gyratory compactors are used to better simulate the field compaction of HMA mixes. The Superpave gyratory compactors (SGC) are designed to meet the specification criteria found in the American Association of State Highway and Transportation Officials (AASHTO) T312 [1,2].

A Superpave mix design involves selecting asphalt and aggregate materials that meet the Superpave specifications and then conducting a volumetric analysis of HMA specimens compacted with the SGC. Previous research has indicated that the precision of this type of a compactor is better than the mechanical Marshall hammer [1]. However, some specific mixtures, such as those containing reclaimed asphalt pavement (RAP) and crumb rubber, have not yet been investigated extensively. Improved understanding of the Superpave mix design of these modified asphalt mixes in the laboratory can be helpful in attaining the experience and techniques for the reuse of these recycled materials in the field.

The volumetric analysis of the Superpave mix design was used in this study to identify the feasibility of these recycled materials in the laboratory. Previous studies have focused on the evaluation of voids in the mineral aggregate (VMA) [3–5]. This and other volumetric properties, such as asphalt film thickness, design asphalt content, dust-to-asphalt ratio, percent fine aggregate, and aggregate surface area, can be considered as criteria for the Superpave mix design. Regarding the VMA requirement, McLeod first pointed out that both the design and analysis of asphalt paving mixtures should be based on a volumetric basis instead of weight [6]. Since then, the VMA requirements have become a standard mixture design requirement and were adopted as a standard in Superpave mix design [3,7].

Although some researchers considered that the minimum VMA criterion is so restrictive that it is difficult to produce acceptable economical mixtures in the field [8], a study by Kandhal and Chakraborty recommended that the aggregate film thickness and aggregate surface area be considered as an alternate for mix design [9]. McLeod also stated his case for using the bulk specific gravity and effective asphalt content for volumetric analysis of the mixture [6]. He pointed out that if the compacted paving mixture was restricted to 3–5% of air voids, this would require a void filled with asphalt (VFA) in the range of 75–85%. Furthermore, he suggested that the VFA requirement would allow a pavement to be constructed with 3.76% asphalt, which he felt was too low for

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durability. The minimum VMA requirement would ensure at least 4.5% asphalt and provide adequate durability [10].

2. Background

In the United States, the Federal Highway Administration (FHWA) reported that 80.3 of the 100 million metric tons of asphalt pavement removed each year during resurfacing and widening projects are reused as part of new roads, roadbeds, shoulders and embankments [11]. The recycling of existing asphalt pavement materials produces new pavements with considerable savings in virgin materials, cost, and energy. Furthermore, mixtures containing RAP have been found, for the most part, to perform as well as virgin mixtures. The National Cooperation Highway Research Program (NCHRP) report 452 provided basic concepts and recommendations concerning the components of mixtures, including new aggregate and RAP materials. The Superpave Mixtures Expert Task Group of the FHWA developed interim guidelines for using RAP based on past experience [12]. In NCHRP Project 9-12 [13], the use of the tiered approach for RAP was considered appropriate. Relatively low levels of RAP can be used without extensive testing of the binder, but when higher RAP contents are desirable, conventional Superpave binder tests must be used to determine how much RAP could be added or which grade of virgin binder is recommended to be added to the mixture.

Meanwhile, there were more than 300 million scrap tires generated in the United States in 2006 [14]. Rubberized asphalt, the largest single civil engineering market for crumb rubber, is being used in increasingly large amounts by several Departments of Transportation (DOT) (e.g. Arizona, California, Florida, Texas, and South Carolina). Most experiments of asphalt containing crumb rubber show improvements in durability, crack reflection, fatigue resistance, skidding resistance, and resistance to rutting not only in an overlay mix, but also in stress absorbing membranes [15–18]. There are two approaches to produce the crumb rubber. The ambient process often uses a conventional high powered rubber cracker mill set with a close nip and vulcanized rubber is sheared and ground into a small particle. The process produces a material with an irregular jagged particle shape. However, the cryogenic grinding usually starts with chips or a fine crumb. This is cooled using a chiller. The rubber, while frozen, is put through a mill. The cryogenic process produces fairly smooth fracture surfaces.

The goal of this study was to investigate the feasibility of using the Superpave gyratory compaction for rubberized asphalt mixtures containing RAP through volumetric analysis of various mixtures with respect to rubber type, percentage, and RAP percentage in the mixture. Experiments were carried out to evaluate the HMA compacted bulk specific gravity (G_{mb}), optimum modified binder content, VMA, and VFA of each RAC and/or RAP mixture.

3. Experimental program and procedures

3.1. Materials

In this study, the experimental design included the use of two rubber types (ambient and cryogenic), four rubber contents (0%, 5%, 10%, and 15% by weight of virgin binder), one crumb rubber size (−40 mesh [−0.425 mm]), and four RAP contents (0%, 15%, 25%, and 30% by weight of the modified mixture). Two granite aggregate sources (designated as L and C) were used for preparing samples, and two binder grades, PG 64-22 and PG 52-28, were used for this project. There were a total of 34 Superpave mix designs in this study.

The RAPs were taken from the same geographical area as the new aggregates to ensure that the aggregates in the RAP have similar properties to the new ones. Both RAP sources (L and C) were approved by the South Carolina DOT (SCDOT) and mixed with an original binder equivalent to a PG 64-22 grade.

3.2. Binder mixing

A mechanical mixer was used to blend the rubber and the virgin binder. The crumb rubber was added to the binder using a reaction time of 30 min, a reaction temperature of 177 °C (350 °F), and a mixing speed of 700 rpm. The reaction time of 30 min was considered suitable based on a preliminary study that showed the mixing time did not significantly influence the binder properties, and Xiao [18] presented the dimensional changes of the rubber in various mixing conditions.

3.3. Binder design

The original Superpave mix design system did not address the use of RAP. However, several studies were later conducted on this subject. For example, research has led to the Black Rock Study, the use of the 3-Tier Approach, the use of linear blending, and the development of technician manuals for the use of RAP [12,13]. For this paper, the Superpave system was used to determine the optimum binder contents (OBC) for all mixtures.

A nominal maximum size 9.5 mm Superpave mixture was used for all mix designs. This particular mix design is used as a primary route surface course mix in South Carolina. The SCDOT 9.5 mm Superpave volumetric and compaction specifications, shown in Table 1, were used. The procedures described in AASHTO PP 19 and AASHTO T312 regarding the preparation of HMA specimens were followed. The engineering properties of the binders are presented in Table 2.

The details of the mix design of two RAP sources are shown in Tables 3 and 4. The RAP materials were first oven-dried and sieved to obtain particles with target sizes shown in Table 4. Then, these materials were blended with the virgin aggregate at the specified (target) mixing temperatures [19–21]. The mixture then was heated for about 1 h in order to maintain the target mixing temperature. Finally, the modified binder (rubber and virgin binder) was added to the mixtures and the final mixture was heated for about 2 h before compaction.

In this study, a conventional HMA mixture composed of new virgin binder and new aggregate was used as a control. Table 3 provides the detailed blend information of the mixtures containing two aggregate sources (L, C) with different percentages of RAP. All modified mixture samples, having a diameter of 150 mm and height of around 115 mm, were compacted using a Superpave gyratory compactor with 75 gyrations (N_{design}).

The flowchart of the experimental design is depicted in Fig. 1. Hydrated lime, used as an anti-strip additive, was added at a rate of 1% by dry mass of virgin aggregate. Gradations of the 9.5 mm mixtures are illustrated in Fig. 2. All mixes satisfied the requirements as specified in Table 1 and Fig. 2 for the optimum binder content. When the rubber contents were varied for other mix designs, the same gradation of the aggregate as shown in Fig. 2 was used.

Table 1
SCDOT 9.5 mm Superpave volumetric specifications.

Superpave 9.5 mm mix specifications	
% Max. density at N_{des}	96
% VMA	>15.5
%Voids filled	70–80
% Max. density at N	<89
% Max. density at N_m	<98
Dust to asphalt ratio	0.6–1.2