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Effects of morphological characteristics of aggregate particles on the mechanical behavior of bituminous paving mixtures

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HIGHLIGHTS

- HMA rutting resistance is strongly correlated with coarse aggregate morphology.
- Direct and objective measurements of aggregate shape should be pursued.
- Shape properties characterized at AIMS 2 strongly correlate with rutting resistance.
- Surface texture should be considered in aggregate and HMA specifications.

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ABSTRACT

This study evaluates the influence of morphological properties of aggregates on the mechanical behavior of bituminous mixtures. For that, two aggregates with different characteristics, i.e., round river gravel and crushed gneiss, were used in the research. Laboratory tests were conducted to characterize morphological properties of the aggregates following traditional methodologies and using a modern image analysis system, AIMS 2. Six asphalt mixtures containing different proportions of gravel and crushed gneiss were designed according to the Superpave methodology and evaluated in mechanical performance tests. The results obtained indicated that aggregate morphological characteristics, especially those of coarse particles, are strongly correlated with the resistance to rutting of the asphalt mixtures. In addition, AIMS 2 was shown to provide more direct and scientific measurements of aggregate morphological characteristics that present higher correlations with the mixture performance than traditional methodologies. Finally, the results also demonstrated that the aggregate surface texture is highly correlated to the performance of the mixtures and should be carefully considered in aggregate and asphalt mixture specifications.

1. Introduction

In order to improve the performance, durability, safety, and efficiency of asphalt mixtures, the Strategic Highway Research Program (SHRP), established in 1987, proposed the Superpave system in 1993. Superpave included a set of significant advancements in the methodologies used to classify asphalt binders and to design asphalt mixtures. In addition, the Superpave system also defined the so-called consensus and source properties of aggregate particles.

The four consensus properties identified by SHRP researchers as key characteristics directly related to the performance behavior of the mixtures were coarse- and fine-aggregate angularity, amount of flat and elongated particles in coarse aggregates, and sand equivalency of fine aggregates. The criteria specified for these properties are generally function of the traffic volume expected in the area where the flexible pavement will be built. On the other hand, the characterization of source properties is considered optional and the corresponding limiting criteria are specified based on the experience of the local transportation agencies to account for the regional geological differences.

Several research efforts have demonstrated reasonable to good correlations between the consensus properties of aggregates specified by the SHRP and the overall mechanical behavior of asphalt mixtures [1–7]. However, in the last years, researchers have

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criticized some of these tests [6,8–13], which are often considered to be subjective and/or based on indirect measurements and to produce results that are a function of the skills of the operator. Some testing procedures, such as the one specified for the determination of the coarse aggregate angularity, can also be tedious and time-consuming.

Considering the relevance of aggregates and the corresponding effects of their properties on the overall behavior of asphalt mixtures and on the costs related to the production and maintenance of flexible pavements, the study of alternative methodologies that are able to characterize aggregates properties in more objective and representative manners becomes a very important task. In that sense, several researchers have adopted protocols to identify aggregate morphological properties based on image analysis techniques, including VDG-40 Videograder, Computer Particle Analyzer, Micromeritics OptiSizer PSDA, VideoImaging System (VIS), Buffalo Wire Works PSSDA, Camsizer, Wipshape, University of Illinois Aggregate Image Analyzer (UIAIA), Aggregate Imaging System (AIMS). Masad et al. [8] compared several of these image analysis systems and identified AIMS as the most promising equipment as it allows a comprehensive, objective, and direct analysis of shape, angularity, and texture based on two-dimensional and three-dimensional images of aggregate particles.

This study evaluates the effects of morphological properties of aggregate particles on the overall mechanical behavior of asphalt mixtures. For that, properties of two aggregates with distinct morphological characteristics, i.e., round river gravel and crushed gneiss, were first characterized based on the specifications of the Superpave system. Alternatively, aggregate morphological characteristics were also determined using the second generation of the modern image analysis system AIMS (i.e., Aggregate Imaging Measurement System 2: AIMS 2). To further identify the effects of the different morphological properties of aggregates on the overall performance behavior of asphalt mixtures, six mixtures comprising different amounts of gravel and crushed gneiss were designed based on Superpave mix design specifications, and their performance behavior was compared to the morphological characteristics of their aggregate skeleton.

Specific objectives of this paper are:

- To characterize aggregate particles with distinct morphological properties based on Superpave specifications and using the image analysis system AIMS 2.
- To characterize the mechanical behavior of asphalt mixtures containing different amounts of gravel and crushed gneiss. For that, three primary mixture characteristics are evaluated: stiffness, permanent deformation, and cracking.
- To identify correlations between the morphological properties of the aggregates evaluated and the mechanical behavior of the corresponding asphalt mixtures.

2. Experimental program

2.1. Materials and mix design

One PG 70-16 S binder obtained from a refinery in Rio de Janeiro, Brazil, and two types of aggregates, i.e., gravel from the state of Pará, Brazil, and crushed gneiss from Rio de Janeiro were used in this study.

Six mixtures with the same aggregate gradation were designed based on Superpave specifications. The first mixture contained crushed gneiss with cubic particles. The second mixture was composed of gravel and natural sand. The use of natural sand as the fine part of gradations containing gravel as coarse aggregates has been a common practice in Brazil and this has been adopted in this research. Three other mixtures were designed and contained the following proportions (by weight) of crushed gneiss and gravel, respectively: (a) 75% and 25%; (b) 50% and 50%; and (c) 25% and 75%. Finally, a sixth mixture composed of crushed gneiss with flat and elongated (F&E) characteristics was also designed. This aggregate was obtained in the same quarry as the cubic crushed gneiss, but processed using a different crushing strategy. Thus, the effect of aggregate morphological characteristics could be better evaluated, given that both cubic and elongated crushed gneisses presented similar geological and physical properties. Fig. 1 shows samples of the three aggregates used in this study.

Tables 1 and 2 present aggregate gradation and volumetric characteristics, respectively, of the six mixtures evaluated in this study, as well as the limiting criteria for a nominal maximum aggregate size of 19 mm and the traffic level between 3 and 10 million ESALs, according with AASHTO M 323 [14]. All mixtures required the same binder content, i.e., $P_b = 4.3\%$ to generate air voids (V_a) between 3.6% and 3.8%.

Mixtures containing higher amounts of gravel presented lower values of voids in mineral aggregates (VMA), which is in accordance with the observation by several researchers [15–18]. Rounded and less angular aggregates generally present smooth surfaces, which in combination to the absence of angular edges facilitates the compaction of the particles in denser structures and reduces the VMA values [15]. The voids filled with asphalt (VFA) were also lower for those mixtures, although within the limits specified by AASHTO M 323 [14].

The percent theoretical maximum specific gravity @ $N_{initial}$ ($\%G_{mm}$ @ N_{ini}) for the mixtures containing gravel was higher than for the mixtures composed of crushed gneiss only, which may indicate a higher sensitivity to the compaction effort during construction and a more unstable behavior under traffic loads. The percent theoretical maximum specific gravity @ $N_{maximum}$ ($\%G_{mm}$ @ N_{max}) decreased as more gravel was added to the mixture, although all mixtures met the specified criterion for this parameter. Finally, all mixtures presented similar dust to binder ratio (D/B) within the allowed limits.

2.2. Characterization of aggregate properties

Morphological characteristics of aggregate particles based on Superpave specifications for consensus properties, i.e., flat and elongated particles (F&E), coarse aggregate angularity (CAA) and fine aggregate angularity (FAA), were first determined. In addition, the test of uncompacted voids described in AASHTO T326 [19] was also performed because several authors have indicated that this test presents better correlation with the mechanical behavior of asphalt mixtures than the typical Superpave CAA test [4,20], which is based on the amount of fractured faces in the aggregate particles. Additional characterizations of the aggregates included the determination of specific gravity, absorption capacity, sand equivalency, and Los Angeles abrasion.

Finally, aggregates were tested in the AIMS 2 system before and after Los Angeles tests to identify their ability to retain the morphological characteristics after abrasion. AIMS 2 is a robust image analysis system that has been used by several researchers to characterize morphological properties of aggregate particles, such as angularity, sphericity, flatness, elongation, and texture. The system combines a high-resolution camera, lighting, and a microscope to perform the analysis. The AIMS 2 turntable uses removable trays, selected by the aggregate size being analyzed, which accommodate the aggregate particles during the tests. An algorithm implemented on the operating software of the system allows the automatic elimination of touching particles and their corresponding characteristics are not reported in the results. This is a very important feature of the system because touching particles can be