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Effects of coarse aggregate angularity on the microstructure of asphalt mixture

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HIGHLIGHTS

- The influence of coarse aggregate angularity on the aggregate contact characteristics and void characteristics of asphalt mixture were analyzed.
- Four indicators, ACN, ACL, AVCI, AHCI, were proposed to evaluate the aggregate contact characteristics.
- The three-dimensional angularity (3DA) could be used to characterize the angularity of coarse aggregate.
- The angularity has a significant influence on the aggregate contact characteristics in the asphalt mixture.

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ABSTRACT

The microstructure characteristic of asphalt mixture has substantial effects on its macroscopic mechanical properties. The study on the structural characteristics of asphalt mixtures involving the microscopic scale has rarely been considered. This study investigates the effects of the angularity of coarse aggregate on the microstructure of two commonly practiced asphalt mixture gradations (AC-16 and SMA-16) based on the X-ray Computed Tomography (XCT). Three-dimensional angularity was introduced based on the XCT images. Four indicators including average contact point number (ACN), average contact length (ACL), average vertical contact index (AVCI) and average horizontal contact index (AHCI) were proposed to evaluate the skeleton contact characteristics within the asphalt mixture through iPas. The volume of air voids, equivalent diameter and roundness were used to characterize the void characteristic of the asphalt mixtures with different angular aggregates by the analysis of Image-Pro Plus (IPP). The results indicate that the three-dimensional angularity (3DA) could characterize the angularity of coarse aggregate. The angularity has a significant influence on the skeleton contact characteristics of asphalt mixture, whereas a lower angularity has resulted in weaker skeleton contact characteristics. A skeleton contact characteristic of SMA-16, with a dense coarse aggregate structure, is stronger than AC-16, which belongs to the dense suspension structure. The shape of the voids at the top and bottom of the asphalt mixture specimen is the most complex and irregular, while the shape of air voids in the middle section of the specimen is simple and regular. This study could provide support for the further research and application of microscopic properties of asphalt mixtures.

1. Introduction

Asphalt mixture comprises of multiple components, including aggregate with identified gradation, asphalt binder, and air voids [1–4]. The microstructure mainly includes skeleton contact characteristics and void characteristics of the asphalt mixture. The contact between numerous aggregate particles is an important factor that influences the strength and transmission path of the forces between the aggregates. Meanwhile, the air void is an essential volumetric index; void distribution and geometry have a significant effect on the properties of the mixture. Uneven void distribution and irregular void characteristics reduce the structural capacity of asphalt pavement, durability, high-temperature

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stability and other road performances. A good microstructure guarantees macro performance and the actual performance of the pavement. The percentage of aggregate is typically 95% of the total mass of the asphalt mixture. For this reason, the microstructure performance of asphalt mixtures are greatly influenced by the characteristics of aggregate particles such as grain shape, size, angularity, texture and morphological characteristics [5–7]. Aggregate angularity is defined as the sharpness of corners/nicks. Based on the previous studies, it could directly influence the aggregate packing and rutting-resistant behavior of mixes, hence the durability of pavement. Generally, the rounded aggregate has blunt edges and considered as low angularity criteria [8].

In recent years, valuable researches on the microstructure performances of asphalt mixtures and the characteristics of aggregates have been widely investigated. Moon et al. analyzed the internal microstructure of asphalt mixtures through Digital Image Processing (DIP) of two-dimensional asphalt mixture images, which were then used to obtain a three-phase material model based on the mixtures volumetric properties [9]. Souza et al. selected five mixtures with different combinations of coarse and fine aggregate angularity, and investigated the influence of aggregate angularity on the mixture's performances and characteristics with the indirect tensile fracture energy test and the uniaxial static creep test [10]. Mahmoud et al. evaluated aggregate shape characteristics including angularity, texture and dimension using Aggregate Imaging System (AIMS), and addressed four issues concerning AIMS measurements [11]. Kane et al. assessed three different types of aggregate to study the relationship between the mineralogical composition of aggregates and the road performance after the polishing action of traffic [12].

However, the polishing process, stage crushing and aggregate production process of aggregates affect their morphological properties, which affect the microstructure of asphalt mixture. Therefore, several research efforts on aggregates have been carried out in different aspects, which include laboratory measurements, imaging-based analysis and mathematical analysis [13–15]. Rajan et al. compared aggregate shape parameters and laboratory performance of coarse aggregates produced from two different types of crushing operations and investigated the effects of different crushing stages on morphology of coarse and fine aggregates [8,16]. Wu et al. evaluated the skid resistance of asphalt pavement with laboratory test results. Twelve typical asphalt wearing course mixtures with different combinations of aggregate sources and mixture types were considered during the tests [17]. Huang et al. used coarse gravels at five different angularity levels and three different asphalt binders to produce mixtures with similar aggregate gradations to evaluate the coarse aggregate angularity (CAA) through uncompacted voids in coarse aggregate (VCA) and tri-axial shear tests [18]. Tashman et al. used different gradations and compaction efforts to prepare the specimens using the Superpave Gyratory Compactor (SGC), characterized the air void distribution by the X-ray Computed Tomography (XCT) system along with image analysis techniques [19]. Liu et al. analyzed sixteen types of coarse aggregates from different quarries in Virginia using the improved FTI system and investigated the correlation between morphological characteristics and uncompacted void content of coarse aggregates [20]. Masad et al. characterized the air void distribution using X-ray tomography images and studied the evolution of the internal structure of AC mixtures during laboratory compaction by the SGC [21]. Wang et al. chose eleven types of aggregates with different variables in their mineralogical properties, investigated the morphological properties of different road surfacing aggregates, including sphericity, angularity and texture [22,23].

Many studies use image analysis systems to evaluate the changes of angularity and texture before and after polishing [24–27], some researches use Finite Element Models (FEM) to evaluate the aggregate morphology, and to study the macroscopic properties of asphalt mixture [28,29]. The characteristics of morphological parameters were determined by a two-dimensional analysis based on the AIMS, and a three-dimensional (3D) parameter prior to characterizing the shape of the aggregates using XCT [30,31]. However, most of the research is based on a two or three-dimensional scope. This indicates that the assessment of the coarse aggregate is mainly dependent on the orientation, and it is not quantitative. Meanwhile, the effects of coarse aggregate angularity on the skeleton contact characteristics and volume of the air voids of asphalt mixture are rarely studied. Therefore, a simulative method of measuring morphological properties of coarse aggregate should be proposed. An analysis method such as iPas and analysis of Image-Pro Plus (IPP) have been incorporated to analyze the influence of coarse aggregate angularity within the microstructure of asphalt mixtures.

2. Objective and scope

The flowchart of research plans is shown in Fig. 1. The scope of this study is as follows:

(a) Coarse aggregate angularity is determined with the quantitative characterization methods through X-ray Computed Tomography (XCT).
(b) The skeleton contact characteristics of asphalt mixture are evaluated through iPas by four proposed indicators.
(c) The void characteristics of asphalt mixtures with different angular aggregates are investigated using the analysis of Image-Pro Plus (IPP).

3. Materials and methods

3.1. Materials

The coarse aggregate, fine aggregate and mineral filler used in this study were limestone, which produced in Huxian County, Shaanxi Province, China. The performance indexes are shown in Tables 1–3 [32]. A virgin asphalt binder (SK-90#, also known as penetration grade 90) was selected, and its basic properties are shown in Table 4.

In order to study the effect of coarse aggregate angularity on the skeleton contact characteristics and void distribution characteristics of asphalt mixture, it is necessary to use the coarse aggregate with different angularity and other similar properties to make

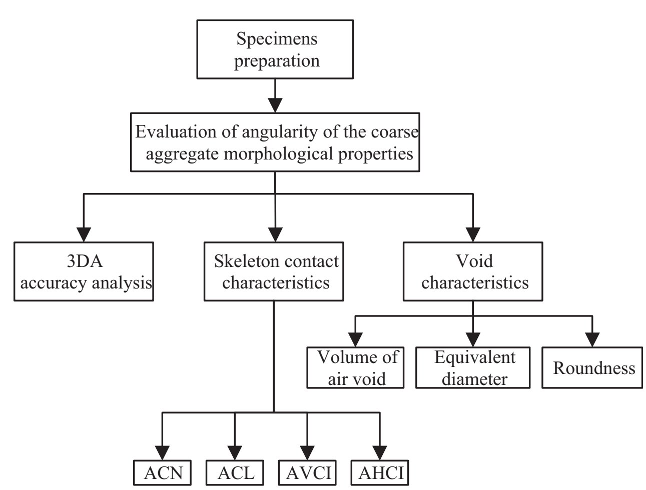

Fig. 1. Flowchart of research plans.