Triaxial virtual shear test of coarse aggregate based on PFC3D

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Abstract. Coarse aggregate has a profound effect on the performance of asphalt mixture. Considering that it is difficult to study the migration and evolution of coarse aggregate in the process of compaction in laboratory tests, this paper investigated the mechanical properties of the aggregate through triaxial virtual tests based on the static pressure molding specimen, which provides a basis for further study on the micromechanical compaction mechanism and mechanical properties of asphalt mixture, and provides a reference for the design method and other forming methods of asphalt mixture based on micromechanics.

1. Introduction

Aggregate is an important component of asphalt mixture. In the compaction process of asphalt mixture, the spatial position of aggregate changes, making the loose material evolve into a dense material with certain strength [1]. Yang et al. comparative analyzed the simulation results and the laboratory test results, which verify the reliability of the model through the discrete element numerical simulation of the triaxial shear test of asphalt mixture with PFC2D. However, this research was based on the two-dimensional microscopic model, and there were few studies on the more complex three-dimensional models [2]. Sha et al. studied the motion characteristics of coarse aggregate in the compaction process of asphalt mixture based on digital image processing technology, which deepened the understanding of the movement law of aggregate. However, the cutting of the test specimens will destroy the integrity of the test piece, and it is difficult to obtain the corresponding image information from the horizontal, vertical and other directions to analyze the movement of the aggregate [3]. Yang et al. simulated and analyzed the formation and development mechanism of asphalt mixture rutting and studied the relationship between coarse aggregate and pavement performance from the microscopic level with PFC2D. But the migration and evolution law of coarse aggregate in the compaction process were not studied [4].

To solve above problems, the mechanical properties of the specimens were studied by triaxial shear test based on discrete element PFC3D, which based on the study of the law of aggregate motion and the static pressure molding aggregate specimens were regarded as the analytic target in this paper. It provided a reference for studying the compaction mechanism and mechanical properties of asphalt mixture from the microscopic level.
2. Triaxial virtual test method
In this paper, the static pressure molding specimens were used in triaxial virtual test. Therefore, there was a certain initial stress inside the specimen and this initial stress cannot be digested by the CYCLE command. As the compaction displacement increases, the initial stress becomes larger. When the compaction displacement is 30mm (20% of the specimen height), the internal initial stress (axial stress) is too large. The particles will escape and resulting in low computational efficiency if this specimen was selected as the research object of the triaxial test. Therefore, a 7.5mm compaction displacement specimen is adopted. At the same time, the confining pressure of the triaxial virtual test is equal to the axial stress of the hydrostatic specimen, and other parameters of the material are the same as the hydrostatic model.

The triaxial virtual shear test of aggregate was realized by numerical servo control system in which the target confining pressure was achieved through the wall speed referring to [5], The upper and lower walls are used to simulate the loading plate, and the side walls are used to apply constant confining pressure devices. In the test, the effect of loading was achieved by specified a certain speed to the upper and lower walls, and the constant confining pressure on the specimen was achieved by the side walls continuously adjusted in the radial direction. The servo control algorithm of constant confining pressure is as follows:

The wall moves at a certain speed so that the aggregate particles interact with the wall to produce a force \( \sigma^{(w)} \), which can be calculated according to the equation (1):

\[
\sigma^{(w)} = \sum_{i} \frac{F^{(w)}_{i}}{A}
\]

Where, \( F^{(w)} \) is the force exerted by particles on the wall, \( A \) is the area of contact between the wall and particles, \( N_{C} \) is the number of contacts between walls and particles.

In order to reduce the error between the current wall stress and the target stress, the velocity of the wall is:

\[
\dot{\sigma}^{(w)} = G(\sigma^{(w)} - \sigma^{(t)}) = G \Delta \sigma
\]

Where, \( \Delta \sigma \) is the stress difference, \( G \) is the motion parameter of the wall, which can be calculated according to equation (3):

\[
G = \frac{\alpha A}{K_{n} \Delta t}
\]

Where, \( K_{n} \) is the contact stiffness, \( \alpha \) is the safety factor, generally 0.5, \( \Delta t \) is the calculation time increment.

In order to better simulate the flexible lateral limit, the lateral wall stiffness is generally 10% of the actual particle stiffness. The parameters recorded in the process of discrete element simulation analysis mainly include confining pressure, deviatoric stress, axial strain and volumetric strain, etc.

(a) AC-13 confining pressure 184Kpa  (b) OGFC-13 confining pressure 753Kpa
3. triaxial virtual test results

The triaxial test can be used to evaluate the compaction effect of the aggregate and establish the relationship between the compaction process and mechanical properties, since the confining pressure of the test is the working condition of the aggregate specimens after static pressure. In the whole test, the confining pressure fluctuation range of AC-13 was slightly larger, but the overall confining pressure remained constant, and the confining pressure of OGFC-13 and SMA-13 specimens was very stable, indicating that the numerical servo automatic control technology was feasible. The deviatoric stress of the specimen showed a little difference, among which OGFC-13 and SMA-13 had a small difference, about 100KPa, and a significant difference with AC-13. The specimens did not consider the influence of fine aggregate. It can be found from the gradation of virtual specimens in Fig. 1 that the content of 2.36mm and 4.75mm of AC-13 is much higher than OGFC-13 and SMA-13. However, the proportion of large particle size of OGFC-13 was slightly larger than SMA-13, but the difference between the two was small in general.

In the process of the test, the contact force tends to be transferred to the particles with large particle size, which eventually leaded to the contact force of the coarse particles being greater than the aggregate with small particle size. According to particle interference theory and micromechanics theory, the small particle size aggregate in a proper amount can increase the coordination number between the particles of the aggregate, and transfer part of the contact force of the coarse aggregate to the fine particles. However, excessive small size aggregate will change the aggregate skeleton structure [6-8]. At the same time, the confining pressure has great influence on the deviatoric stress of the specimen. The relationship between the compacted stress and strain of the specimen under the joint influence of confining pressure and internal structure of the specimen as shown in Fig. 1. From the figure, the order of deviatoric stress from large to small is: OGFC-13>SMA-13>AC-13. Due to the lack of fine particles smaller than 2.36mm in the coarse aggregate specimens, although spatial framework structure with a certain strength can be formed with SM-13 and OGFC-13, the shear strength of this structure decreases sharply after the strength reaches the peak, for lacking the filling of fine aggregate.
Figure 2. Volumetric strain vs axial strain at the 7.5mm compaction displacement.

The relationship between the volumetric strain and axial strain of the 7.5mm compaction displacement specimen as shown in Fig. 2. The aggregate volume decreased first and then increased gradually during the experiment. The triaxial test process of coarse aggregate has two stages: compression and dilation. The initial stress and aggregate type of the specimen have certain influence on the relationship between the volumetric strain and axial strain, but they do not change the above two stages.

The surface texture of aggregates belongs to the characteristics of microscopic geometry, which is mainly manifested as the roughness of aggregates. Generally speaking, the aggregate with rough surface has good texture while the friction angle between the aggregates is large. Therefore, the texture of aggregate is closely related to the pavement performance of asphalt mixture. The surface texture characteristics of aggregates is difficult to simulate by numerical simulation, but it exists objectively. Therefore, the surface texture of aggregates is directly related to the friction coefficient, which is simply used to represent the texture. The better the texture of aggregates, the higher the friction coefficient [9].

Figure 3. Effects of texture on the stress and axial strain curves of SMA-13 specimens.
In order to analyze the influence of aggregate surface texture on shear strength, this paper studied the relationship between stress and strain when the friction coefficient is 0.1, 0.3, 0.5 and 0.7, and the confining pressure is 0.63 MPa, as shown in Fig. 3. In Fig. 3, the friction coefficient is positively correlated with the stress, that is, the greater the friction coefficient is, the greater the deviatoric stress of the specimen will be, that is, the greater the axial stress will be when the specimen is destroyed. It is indicated that the better the aggregate surface texture is, the stronger the load resistance of the specimen is. Therefore, the aggregate with good texture should be chose in the design of asphalt mixture.

4. Conclusion
In this paper, the mechanical properties of static compression specimen were evaluated through triaxial virtual test based on the discrete element model of coarse aggregate static pressure. The conclusion as follows:

(1). The order of deviatoric stress from large to small is: OGFC-13>SMA-13>AC-13. In the process of aggregate test, the volume strain is divided into two stages: compression and diastolic. The friction coefficient has a great influence on the deviatoric stress, but does not change the rule of aggregate volume strain.

(2). The evaluation provides a basis for further study on the mesoscopic compaction mechanism and mechanical properties of asphalt mixture, and provides a certain reference for the design method and other forming methods of asphalt mixture based on mesoscopic.

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