Analysis of the effect of gradation and maximum nominal particle size on coarse aggregate movement

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Abstract. The formation of ruts is closely related to the movement of the aggregate. In order to analyze the movement law of the aggregate during compaction, this paper based on the discrete element model, the coordination number, void ratio, average contact force, and axial stress are used as indicators to investigate the effects of gradation and maximum nominal particle size on the law of aggregate movement. The influence of material parameters on aggregate movement was explored from the microscopic level so as to provide suggestions for design grading and improving rutting resistance of asphalt pavements.

1. Introduction
Asphalt pavement is widely used in the road structure because of its excellent performance. Under the action of high temperature and repeated load, the asphalt pavement is prone to rutting and other diseases. The macro shape of the rut is formed by the particles inside the asphalt mixture undergoing complex microscopic movements [1]. Among them, the movement of coarse aggregate plays an important role, and the movement of coarse aggregate is affected by factors such as gradation type, maximum nominal particle size, and aggregate stiffness [2]. At present, the research on rutting only focuses on prevention, and there are no less expensive repair methods.

The prevention of rut is mainly carried out from two aspects, active and passive. Active prevention is mainly achieved by reducing the temperature of the pavement. Cao [3] applied a heat reflective coating on the surface of the asphalt mixture, which improves the heat reflection ability of the mixture and reduces the temperature. Tian [4] mixed phase change materials into asphalt mixture by replacing fine aggregate with constant volume, and reduced the temperature by absorbing heat through phase change. Passive prevention is achieved by improving the rut resistance of the pavement. Shafabakhsh [5] added nano-TiO2 to the asphalt mixture has improved the rut resistance of the asphalt mixture. Chen [6] proposed a multi-stage coextrusion design method for coarse aggregates based on the combination of filling theory and interference theory. The secondary particles are filled into the skeleton formed by the upper particles. The filling rules are determined by the compactness of the system.

In order to analyze the movement rule of aggregate during compaction, the rutting resistance of asphalt pavement can be improved from the point of gradation. In this paper, based on the discrete element model, the effects of the gradation type and the maximum nominal particle size on the aggregate motion were studied by taking the coordination number and void ratio, average contact force and axial stress as indicators. The influence of material parameters on aggregate movement was investigated from the microscopic perspective, in order to provide suggestions for designing gradation and improving the rutting resistance of asphalt pavement.
2. Model establishment

The model in this paper adopts the author's previous research results [7], as shown in Figure 1, and the grading of the virtual specimens is shown in Table 1.

![Aggregate virtual specimen](image)

Table 1. Gradation for virtual aggregate specimen

| Sieve sizes/mm | 16 | 13.2 | 9.5 | 4.75 | 2.36 | 1.18 | 0.6 | 0.3 | 0.15 | 0.075 |
|----------------|----|------|-----|------|------|------|-----|-----|------|-------|
| Passing /100%  | 100| 95   | 65  | 30   | 21   | 19   | 16  | 13  | 12   | 10    |

3. Analysis of gradation and maximum nominal particle size of coarse aggregate movement

3.1. Maximum nominal particle size

SMA-10 and SMA-16 adopt the intermediate gradation recommended by the Technical Specification for Highway Asphalt Pavement Construction (JTG F40-2004).

3.1.1. Void ratio and coordination number. The initial void ratio of the material has a large effect on the mechanical response of the unbonded material, so the average initial void ratio of different virtual specimens is the same to facilitate comparison and analysis of the models. Aggregate is a granular material, and the void ratio varies with the boundary effect, gradation type and feeding method of the test piece. According to Figure 2, the maximum nominal particle size has a small effect on the distribution of the void ratio.

![Effect of maximum nominal particle size on void ratio](image)
The changes of coordination number under different particle sizes are shown in Figure 3. The final coordination numbers of SMA-10 are basically the same. The former is slightly larger than the latter in the initial state. The coordination number of SMA-10 has little difference between before and after compaction. The initial coordination number of SMA-16 is slightly less than that of SMA-10, but the final coordination number is significantly different: the coordination number of SMA-16 is less than 6, while the coordination number of the other two specimens is close to 7.

### 3.1.2. Average contact force and axial stress

The average contact force and axial stress have a good correlation, as shown in Figure 4. In essence, the average contact force is the force formed between individual particles and belongs to the category of micro-meso; the axial stress is the macroscopic expression of the corresponding contact force. According to the calculation time step analysis of the model, it takes the longest time to reach the same compaction displacement SMA-16, and the shortest is SMA-10. Studies show that coarse particles easily form a strong spatial skeleton structure to resist the outside load effect. From the perspective of the average contact force and axial stress, the contact force of the SMA-16 mixture is also significantly greater than other mixtures. Therefore, it is proved from the mesoscopic level that the coarse aggregate gradation type can reduce the rutting disease in areas with high temperature and high temperature duration.
3.2. Gradation type
AC-13 and OGFC-13 were selected as the research objects to investigate the effects of gradation types on aggregate movement and mechanical properties.

3.2.1. Coordination number and void ratio. The coordination number of the mixture is between 6 and 7. Generally speaking, there is no significant difference between the coordination number of the OGFC-13 specimen in the horizontal and vertical directions, as shown in Figure 5.

The void ratio distribution law is generally expressed as follows: AC-13 void ratio distribution is more uniform; OGFC-13 has the lowest void ratio in the horizontal middle area, and there is no significant difference in the vertical direction, as shown in Figure 6. The results show that: in the horizontal direction, the particle system force is transmitted from both ends to the middle, and the contact force gradually decreases during the transmission process, so the void ratio in this area is large.
3.2.2. Average contact force and axial stress. The average contact force of OGFC-13 is about 140N, and the average contact force of AC-13 is about 100N. It can be seen that the contact force of OGFC-13 is greater than AC-13; the relationship between the axial stress is that OGFC-13 is greater than AC-13 (Figure 7). OGFC-13 contains coarse aggregates, but few fine aggregates, which belongs to a typical suspension skeleton structure. The contact force is always transmitted along the large particles, and it is easy to form a skeleton structure, so that it has greater contact force and axial stress.

4. Conclusion
This paper discusses the migration and evolution of aggregates based on the discrete element model of static pressure of coarse aggregates. The main conclusions are as follows: The maximum nominal particle size has a small effect on the distribution of the porosity, but it has a certain effect on the
coordination number. In the same volume, the smaller the particle size, the larger the coordination number. The maximum nominal particle size is positively related to axial stress and contact force.

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