Analysis of influence of aggregate stiffness on coarse aggregate movement of asphalt mixture

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Abstract. The movement law of aggregate is more complicated in the static pressure process of asphalt mixture. In order to analyze the evolution law of the aggregate, the objective of this paper is to develop 3D (3-dimensional) mixture compaction models. The coordination number, void ratio, average contact force, and axial stress are used as indicators to investigate the effects of aggregate stiffness 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 the design of graded.

1. Introduction

Asphalt mixture is a multiphase system material composed of aggregate, asphalt cement and voids[1]. The mechanical strength of the asphalt mixture is directly related to the spatial structural characteristics such as the distribution of aggregate particles and the contact state between the aggregates[2]. The formation of the spatial structure of the asphalt mixture largely depends on the compaction molding process. How to ensure that the asphalt mixture is fully compacted is a problem that road workers pay attention to.

The movement and evolution of the coarse aggregate are part of the main factors affecting the compaction of asphalt mixtures. J Li[3] used the digital speckle correlation method to perform sub-pixel search with high theoretical accuracy, but it relied heavily on image quality. Y J Qiao[4] attached the grid target to the surface of the test piece and established the displacement field on the surface of the test piece by capturing the corners of the target. P L Li[5] incorporated labeled aggregates into the asphalt mixture, and tracked the marked aggregates using X-ray CT, but it was limited by the number of samples and evaluation indicators. X G Shi[6] established a two-dimensional discrete element model of asphalt mixture, and analyzed the particle contact characteristics and stress transfer law under load; D Y Zhang[7] carried out three-dimensional discrete element simulation of uniaxial creep test of asphalt concrete and estimated the creep behavior of asphalt concrete.

None of the above methods consider the influence of material parameters on aggregate displacement. For this purpose, based on the discrete element model, the coordination number and void ratio, average contact force, and axial stress are used as indicators to investigate the effects of stiffness, gradation type 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 the design of graded.
2. Model establishment and measuring ball arrangement
Discrete elements are used to simulate the mechanical properties of asphalt mixtures generally regard asphalt mixtures as consisting of coarse aggregate (≥2.36mm), asphalt mortar (<2.36mm fine aggregate, filler and asphalt) and voids in domestic and foreign literatures. Based on this idea, the virtual aggregate specimen is considered to be composed of coarse aggregate and void. The gradation in Table 1 was used as the research object, and the generated coarse aggregate and void two-phase virtual specimen was shown in Figure 1. The void fraction formed between coarse aggregates is relatively large, while the contact number between aggregates is not large. The vertical and horizontal profile analysis shows that the void fraction is evenly distributed, and the void fraction of aggregates is 39.6% through programming test. The model is based on the author's previous research [8].

| 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    |

(a) Coarse aggregate specimen  
(b) Vertical section  
(c) Horizontal section

Figure 1. Aggregate virtual specimen

Void fraction and coordination number are monitored by measuring balls, as shown in Figure 2. The diameter of the measuring balls should not be less than 2 times of the maximum nominal particle size, and 30mm is taken. Considering the great difference between void fraction and coordination number at the wall boundary, the displacement of the measured balls from the side wall and the bottom wall are 5mm and 10mm respectively. The larger compaction displacement reduces the height of the specimen and affects the arrangement of the measuring balls. Therefore, the upper measuring ball deviates from the loading plate. The spatial distribution of coarse aggregate is complicated, and the void rate and coordination number are different at different locations. Measuring balls are arranged in all directions, and the void rate and coordination numbers of the specimens are the average values of the void rate and coordination numbers monitored by measuring balls.

Figure 2. Measuring ball arrangement
3. Analysis of aggregate stiffness of coarse aggregate migration and evolution law

According to the arrangement of the measuring balls in Figure 2, the test pieces were layered from the horizontal direction and the vertical direction. Among them, there are three layers in the horizontal direction, and each layer contains 5 measurement balls, which are recorded as L1 (17, 8, 18, 7, and 9), L2 (15, 5, 16, 4, and 6), and L3 from top to bottom. (13, 2, 14, 1, 1 and 3); vertical direction is divided into H1 (1, 4, and 7), H3 (3, 6 and 9), and H2 (2, 5, 8, 13, 14, 14, 15, 16, 17 and 18). With a reference stiffness of $1.11 \times 10^6$ N/m, the migration and evolution of aggregates at 2 times the reference stiffness are discussed.

Figure 3. Effect of aggregate stiffness on coordination number

(a) Horizontal direction of reference stiffness

(b) Vertical direction of reference stiffness

(c) 2 times horizontal

(d) 2 times vertical
3.1. Coordination number and void ratio.

With the compaction, the distance between particles gradually decreases and the contact number increases significantly, as shown in Figure 3. In the horizontal direction, the coordination number of the middle part is smaller than that of the two ends, which is related to the transfer of force in the specimen. Force chain is the contact force cross each other to form a system network, for static pressure molding, the middle position of the force chain than other parts of the loose, that is, the contact force between the weak particles less contact point. When the aggregate stiffness increases (2 times, 5 times, 10 times), the coordination number of the position is different at the beginning of the test, but basically the same at the end. The coordination number of the particles in the middle part is less than that at both ends. The results show that the stiffness cannot change the force transfer property.

In the vertical direction, there is no significant difference in the final coordination number. This is actually related to the contact force of particles inside the aggregate. In the vertical direction, measuring balls are set at different heights of the specimen, and the difference of contact force distribution in each region is small. Therefore, the aggregate stiffness has no significant effect on the coordination number in the vertical direction.

Void ratio and coordination number have a certain correlation. Generally speaking, the larger the void ratio of the same specimen, the smaller the coordination number of particles and the smaller the density of the corresponding specimen. During the compaction process, the void ratio of the aggregate specimen keeps changing, as shown in Figure 4. It can be seen from the Figure that in the horizontal and vertical directions, the influence of aggregate stiffness on the evolution law of void ratio is not obvious. In the horizontal direction, the voids in the region are larger than those in other locations, which is consistent with the effect of aggregate on coordination number. The load is transferred through contact force. When the force chain in the middle position is sparse, the displacement between particles is large, which makes the particles cannot be effectively compacted, so the void ratio is large,
3.2. **Average contact force, axial stress and unbalanced force.**

The influence of aggregate stiffness on contact force, axial stress and unbalanced force (UC represents the reference stiffness, UC2 represents twice the reference stiffness, others are similar) is shown in Figure 5. The larger the aggregate stiffness is, the greater the average contact force and axial stress are, and the increment of average contact force and axial stress is consistent with the increment of aggregate stiffness. The larger axial stress and contact force indicate that the aggregate has stronger resistance to external load. The results show that the stiffness of aggregate does not affect the operating efficiency of the system.

### 4. Conclusion

In this paper, based on the coarse aggregate static pressure discrete element model, the macroscopic and mesoscopic contact indicators of aggregate were established during the process of static pressure and the migration and evolution law of aggregate were discussed. The main conclusions are as follows: The stiffness of the aggregate has little effect on the distribution of the coordination number, the void ratio, and the unbalanced force. Aggregate stiffness is positively related to contact force and axial stress.

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### References

[1] A R Coenen, M E Kutay, N R Sefidmazgi and H U Bahia 2012 Aggregate structure characterisation of asphalt mixtures using two-dimensional image analysis *Road. Mater. Pavement.*** 13 433-454

[2] M E Kutay, H I Ozturk, A R Abbas and C C Hu 2011 Comparison of 2D and 3D image-based aggregate morphological indices *Int. J. Pavement. Eng,* 12 421-431

[3] J Li, C Wan and X Cai 2015 Analysis of asphalt mixture particle trajectory based on digital image correlation method *Journal of wuhan university of technology.* 39 591-597

[4] Y J Qiao 2008 Displacement field measurement and fluidity rut analysis of asphalt mixture *Ph.D dissertation, Dalian Univ of Technology.* Dalian, China

[5] P L Li, J F Sun, P Gao, X Wu and J G Li 2019 Analysis of aggregate particle migration properties during compaction process of asphalt mixture *Conster. Build. Mater.* 197 42-49
[6] X G Shi and W Shi 2014 Stress and failure mechanism of asphalt mixture were analyzed from microstructure petroleum asphalt. 28 49-54

[7] D Y Zhang virtual permanent deformation tests of asphalt mixture suing discrete element method Ph.D dissertation, Southeast Univ. Nanjing, China

[8] W D Liu, X Gong, Y Gao and L M Li Microscopic characteristics of field compaction of asphalt mixture using discrete element method J. Test. Eval. 47 4579-4594