Experimental Study on the Characteristics of Air Voids of Asphalt Mixture under Vacuum Compaction

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Abstract. In order to improve the compaction quality of asphalt mixture, a vacuum compaction technology is studied. Under different vacuum degrees (0 MPa, -0.04 MPa, -0.06 MPa, -0.08 MPa and negative pressure), the vacuum compaction process was used to prepare asphalt mixture samples and their characteristics of air voids were tested. The test results show, when the vacuum degree increases from 0 to -0.08 MPa, the air voids decrease with the increase of vacuum degree. The middle and upper air voids are small, and between 9-25 layers, average air voids under vacuum degree of -0.08 MPa and negative pressure is 13.2%, which is 41.6% lower than that under non vacuum; The average diameter is controlled at 1.88~2.19 mm under vacuum degree of 0.08 MPa and negative pressure, which is 43.3% less than that under non vacuum. Those results show that vacuum compaction can effectively improve the characteristics of micro air voids of asphalt mixture, which will also improve the compactness.

Keywords. Asphalt mixture, vacuum compaction, air voids, equivalent diameter, compactness.

1. Introducing
Asphalt pavement has the characteristics of comfortable driving, good flatness and low noise, which is widely used in high-grade pavement in many countries. In recent years, with the increase of vehicle ownership and vehicle load, under the repeated action of driving load, the plastic deformation of pavement gradually accumulates, and the pavement disease gradually appears, which shortens the service life of asphalt pavement. The research shows that in the construction of asphalt pavement, compaction is one of the key factors to determine the pavement quality, and compaction can affect the density, air voids and mechanical properties of asphalt mixture [1-3]. Therefore, in order to further improve the service life of asphalt pavement, many scholars have studied the compaction of asphalt pavement. Gao [4] believed that road performances of asphalt pavement including the designed density, Marshall stability and volumetric properties of asphalt mixtures were significantly affected by the compaction temperature, which needs to be well controlled. Meng [5] proposed that vibration compaction molding and optimization of compaction process can improve the particle coordination number and uniform stress distribution in the mixture, which is conducive to improve the deformation resistance of drainage asphalt mixture. Jiang et al. [6] found that the asphalt mixture compacted by the vertical vibration compaction method has a larger compressive strength and splitting strength than the asphalt mixture compacted by the Marshal compaction method. Besides, Intelligent Compaction (IC) [7-8], has been introduced into the compaction of asphalt mixtures. Chang et al. [9] studied that...
constantly measured the density of the locations where the roller compactor passes, which can improve the compaction quality. Kassem et al. [10] built the compaction monitoring system, which was able to show some inconsistencies in the compaction process such as unequal compaction converge across the mat, non-uniform compaction effort and temperature. However, those compaction methods can not meet the requirements of asphalt pavement, and some improvements need to be made from the compaction principle.

In this paper, a vacuum compaction method for asphalt mixture was proposed. A vacuum compaction device was designed and manufactured. The asphalt mixture samples obtained from it were used to test the characteristics of air voids, which will verify the compaction effect of the method.

2. Experimental Materials and Methods

2.1. Experimental Materials and Processes

Three sizes of aggregates were used in the experiment, and they were 0~4 mm, 4~11 mm and 11~13 mm. The parameters of the aggregates meet the requirements of the "Specification for Construction and Acceptance of Asphalt Pavement" (GB50092—96). The aggregate ratio was obtained according to the requirements of AC-13 asphalt mixture gradation, of which 0~4mm accounted for 30%, and 4~11 mm accounted for 46% and 11~13 mm accounted for 24%. The SK-90 bitumen was selected in the experiment, whose asphalt content was 5%.

In the experiment, two kinds of the vacuum compaction devices (static compaction device A and) were used to produce the samples, as shown in figure 1. They had the same base that opened with a vacuum gauge connection port, which was convenient to observe whether the vacuum degree of the asphalt mixture in the device was consistent. The difference between device A and device B was mainly that the vacuum area was different. The pressure difference between the external atmospheric pressure and the internal vacuum in device B will add an additional force to the asphalt mixture, which changes with the pressure in the device. By adding the asphalt mixture into the vacuum loading device, and controlling the vacuum degree with a vacuum pump, and loading the load, the samples under different working conditions can be obtained. Table 1 shows the test conditions.

![Figure 1. Physical diagram of different vacuum loading devices.](image)

**Table 1. Test conditions.**

| Group           | Parameter Loading force | Vacuum (MPa) | Compaction device |
|-----------------|-------------------------|--------------|------------------|
| Condition 1     | 5.4kN                   | -0.08        | (B)              |
| Condition 2     | 5.4kN                   | -0.08        | (A)              |
| Condition 3     | 5.4kN                   | -0.06        | (A)              |
| Condition 4     | 5.4kN                   | 0            | (A)              |
2.2. Testing Air Voids and Their Characterization

12 samples under 4 working conditions were scanned by CT scanner equipment. The height of each sample is about 78mm, which were scanned from the top of the samples at 2mm/slice intervals. Finally, a total of 39 slices were scanned and 39 CT tomographic pictures were obtained, as shown in figure 2. To ensure the accuracy, the upper and lower layers were abandoned, and a total of 37 layers of data were collected. The image processing function in MATLAB software was used to analyze and process the original image obtained by scanning. First, the original image was converted into binary image by the software, and then the image was analyzed by self-editing MATLAB program to obtain the characteristics of the internal air voids of the asphalt mixture samples under different working conditions, seeing figure 3. Finally, all the working condition data were analyzed.

3. Results and Discussion

3.1. Macro air Voids of Asphalt Mixture under Vacuum Compaction

Figure 4 shows the air voids of asphalt mixture under four working conditions. It can be seen from figure 4 that under different working conditions, the macro air voids of the asphalt mixture are different. In the working conditions of the compaction device A, the air voids of the samples in working condition 4 is the largest, which is 15.1%; with the increase of vacuum degree, the air voids gradually decrease, and it in the working condition 2 is the smallest, which is 11.6%. When the vacuum degree is same, the air voids of the samples in the working condition 1 are less than that in the working condition 2. This is because with the increase of vacuum degree, the "vacuum pressure difference" is formed, resulting in the increase of cracks and active escaping bubbles, which reduces the overall macro air voids of asphalt mixture. Those show that the compaction device B exerts a greater vacuum force than the compaction device A, which makes its vacuum compaction effect more significant. It can be seen that vacuum compaction can effectively reduce the macro air voids of the asphalt mixture and improve the compaction quality. The results show that the larger the vacuum degree is, and the smaller the macro air voids of asphalt mixture are and the better the compaction effect is.
3.2. The Layered Air Voids of Asphalt Mixture

Figure 5 shows the variation of the air voids of the asphalt mixture with the number of layers under different working conditions. It can be seen from figure 5 that the air voids of each layer inside the samples under the same working condition varies greatly along the vertical direction. The air voids gradually decrease from the top to a certain layer and then gradually increases. The curve of condition 1 is located at the far left, followed by condition 2, then condition 3, and condition 4 is at the far right. On the whole, the middle and upper air voids are small, and between 9-25 layers, average air voids of working condition 1 is 13.2%, and that of working condition 2 is 16.3%, and that of working condition 3 is 20.8%, and that of working condition 4 is 22.6%. The air voids of the upper surface layer are larger due to it is direct contact with the pressing plate to bear greater pressure, and the aggregates are likely to be squeezed into each other under the compressive force. When the air voids reach the minimum value, they increase gradually because the compaction energy decreases with the increase of depth. It means that under the same test conditions, as the degree of vacuum increases, the average air voids of each layer of the asphalt mixture sample gradually decrease.

3.3. The Size of the Air Voids in the Asphalt Mixture

Figure 6 shows the variation of the average equivalent diameter of asphalt mixture air voids with the number of layers under different working conditions. Under the same working conditions, the average equivalent diameter of the internal air voids of the asphalt mixture samples changes significantly along the vertical depth direction. The equivalent diameters of the voids at both ends are relatively large, and the overall trend of change is gradually decreasing from the top to a certain layer and then gradually
increasing. Those show a distribution of "small at the upper end and big at the lower end". Compared with different working conditions, the average equivalent diameter of the air voids in working condition 1 is the smallest and that of in working condition 4 is the largest. From the 9-25 layers, the average diameter is controlled at 1.88~2.19 mm under working condition 1, and it is 2.33~2.62 mm under working condition 2, and it is 2.86~3.84 mm under working condition 3, and it is 3.46~4.13 mm under working condition 4. Those results indicate that the sizes of internal air voids of the asphalt mixture can be controlled, and the vacuum degree is the larger, which will obtain the smaller the average sizes of the air voids of asphalt mixture and the higher the compactness.

![Figure 6. Average equivalent diameters of the air voids of asphalt mixture under different working conditions.](image)

Therefore, the test results of the air voids, the number of air voids and average equivalent diameters of air voids in each layer show that vacuum compaction can effectively improve the characteristics of micro air voids of asphalt mixture. With the increase of vacuum degree, the micro air voids and average equivalent diameters of air voids of asphalt mixture gradually decrease, which is consistent with the test results of macro air voids.

4. Conclusion

In this paper, two vacuum compaction devices were designed and fabricated, which were used to prepare to the samples of asphalt mixtures to test their air voids. The conclusions are as follows:

1. When the vacuum degree increases from 0 to -0.08 MPa, the air voids decrease with the increase of vacuum degree. When there is external negative pressure, the air voids are smaller and the compactness is greater.

2. On the whole, the middle and upper air voids are small, and between 9-25 layers, the average air voids under vacuum degree of -0.08 MPa and negative pressure is 13.2%, and that under vacuum degree of -0.08 MPa is 16.3%, and that under vacuum degree of -0.04 MPa is 20.8%, and that under non vacuum is 22.6%.

3. From the 9-25 layers, the average diameter is controlled at 1.88~2.19 mm under vacuum degree of 0.08 MPa and negative pressure, and it is 2.33~2.62 mm vacuum degree of 0.08 MPa, and it is 2.86~3.84 mm under vacuum degree of 0.04 MPa, and it is 3.46~4.13 mm under non vacuum.

Acknowledgments

This work is supported by Science and Technology Entrepreneurship Leading Project of Zhongyuan, Science and Technology Innovation Leading Project of Zhongyuan (194200510029) and Fundamental Research Funds for the Central Universities of China (No. 310825163408).
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