Study on Volume Index Test and Control of Large Stone Porous Asphalt Mixture

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Abstract. Due to the large proportion of coarse aggregate, the key index void ratio of Large stone porous asphalt mixture is difficult to control in the production process. In order to solve this problem, this paper first carries out the raw materials testing and mixture design of LSPM-30; then carries out the comparative analysis of the calculation method and Corelock method for the volume index of Large stone porous asphalt mixture; finally, according to the sample test and porosity calculation, the difference of porosity between the laboratory sample and the field sample is calculated, and based on this, the porosity of the field and laboratory sample is proposed control requirements.

1. Introduction
Large stone porous asphalt mixture (LSPM) is a kind of asphalt mixture with the maximum nominal particle size greater than 26.5mm, which has a certain porosity and can drain water out of the pavement structure freely. The LSPM is usually used as the base course of pavement structure. Large stone porous asphalt mixture has good drainage effect, which is usually semi open graded (porosity is 13-18%). It has good anti rutting ability, good drainage function, and can effectively reduce reflection cracks [1].

Due to the characteristics and functional requirements of LSPM structure layer, the control of material void ratio becomes the key link of structural layer. Due to the large proportion of coarse aggregate and less cementitious materials, the porosity of large stone porous asphalt mixture asphalt mixture is difficult to control in the production process [2]. On the one hand, the applicability of existing asphalt mixture density testing methods to LSPM needs to be studied. On the other hand, field coring is different from laboratory molding method. The structural depth of side surface of laboratory formed specimen is significantly greater than that of field cutting core sample. This situation is amplified in the LSPM asphalt mixture, a special material with large proportion of coarse aggregate. In view of these two factors, this paper carried out research respectively [3].
Figure 1. Large diameter drainage mixture is used for blind drainage ditch

2. Raw material

(1) Asphalt binder

In order to ensure the durability of LSPM asphalt mixture, the mixture needs relatively thick asphalt film, but at the same time, it must prevent the mixture from leaking out. Therefore, asphalt binder with high viscosity should be used. In this paper, MAC-70# modified asphalt is used.

(2) Aggregate

Limestone with regular grain shape is selected as coarse and fine aggregate and filler for LSPM. Through test, all technical indexes of aggregate meet the standard of technical specification for application of LSPM.

3. Mix proportion design of LSPM-30 mixture

Due to the special characteristics of LSPM, there is no fixed gradation range. The gradation is determined according to the properties of raw materials, which basically belongs to the skeleton inlay of single large particle size aggregate.

The large Marshall method and rotary compactor method can be used for the formation of LSPM. The mixture design adopts large Marshall compaction method, with 112 times of double-sided compaction and 3.1% of asphalt content. The mixture test method refers to the test specification for asphalt and asphalt mixture of Highway Engineering (JTG E20-2011). The final mix gradation is determined as follows.

| Mesh size /mm | 31.5 | 26.5 | 19 | 13.2 | 9.5 | 4.75 | 2.36 | 1.18 | 0.6 | 0.3 | 0.15 | 0.075 |
|---------------|------|------|----|------|-----|------|------|------|-----|-----|------|-------|
| upper limit   | 90.0 | 70.0 | 40.0 | 28.0 | 19.0 | 6.0 | 6.0 | 3.0 | 2.0 | 1.0 | 1.0 | 1.0 |
| lower limit   | 100.0 | 95.0 | 76.0 | 58.0 | 39.0 | 29.0 | 18.0 | 15.0 | 10.0 | 7.0 | 6.0 | 4.0 |
| Composite gradation | 100.0 | 96.3 | 63.5 | 40.0 | 30.5 | 16.3 | 8.4 | 6.0 | 4.5 | 3.3 | 2.6 | 1.8 |

The results of Schellenberg Binder Drainage Test and Cantabro Test of formed mixture meet the requirements of technical specification for application of LSPM.

4. Comparison of different porosity test methods

The main volume index of LSPM is void ratio, which is the key point to realize the function and durability of structural layer. According to the characteristics of LSPM, the measurement method and calculation method are used in this study. The core Lok method, which is advanced internationally, is used to measure the density of the mixture with large porosity.

(1) Calculation method
The calculation method is a method to calculate the void ratio of mixture by testing the density and water absorption of different materials of mixture. This method is also the main method of mixture proportioning design and site porosity control.

(2) Measurement method

The basic principle of Corlock is that the air in the opening gap of asphalt mixture or aggregate is extracted by vacuum packaging, and then the various density and volume characteristics of asphalt mixture or aggregate can be calculated by weighing the mass of air and water. This method has the characteristics of fast, accurate and good reproducibility, but it is rarely used in China due to equipment limitation. Corlock equipment is shown in the figure below.

A total of 31 groups of large-scale Marshall specimens were prepared by compaction method for LSPM. In this paper, the porosity test was carried out on 31 groups of samples by calculation method and measurement method respectively. The 31 groups of samples were processed by 3cm double-sided cutting, and the corresponding relationship of porosity was linearly fitted with Corelock method as reference, as shown in the figure below.

![Corelock equipment](image)

**Figure 2.** Corelock equipment

![Comparison of measured and calculated voids](image)

**Figure 3.** Comparison of measured and calculated voids
From the above figure, it can be seen that the fitting curve between the measured and calculated voids of Corelock method is close to that of calculation method when the porosity is about 19%. Therefore, the deviation on both sides of the void ratio calculated by the test piece calculation method is about 19%. When the porosity of core sample measured by calculation method is within 8.5 ~ 15%, the corresponding porosity of Corelock method can be controlled within 13 ~ 18%, which means calculation deviation. When the porosity of core sample measured by the method is more than 15.5%, the compactness of the approximate ratio is insufficient, and there is a risk of insufficient high temperature stability. Therefore, when the void ratio of LSPM specimen is tested by calculation method, the void ratio is controlled in the range of 8.5 ~ 15%, and the volume index of mixture has good assurance rate.

5. Research on void ratio control of LSPM

In the construction process, the compactness and void control of asphalt pavement are mainly obtained by core drilling sampling, but the porosity of core samples obtained from LSPM often deviates from the theoretical data obtained in the laboratory, which makes it more difficult to control the porosity in site construction. According to the analysis of the research group, there are two main reasons for this situation: first, the proportion of coarse aggregate of LSPM is large, the porosity is large, and the binding effect of binder is limited, so the aggregate is easy to collapse in the process of core drilling, and it is difficult to obtain a complete core sample; second, the field coring method is different from the laboratory molding method, and the surface structure depth of laboratory molding specimen should be clear. This situation is magnified in the LSPM, which has a large proportion of coarse aggregate. The second factor should be the main factor of error, which should be corrected.

5.1. Calculation of surface porosity of test piece

In order to explore the surface void of LSPM, the research group considered cutting the surface of core sample and testing the porosity of core sample by calculation method, and then calculate the time surface porosity.

In this test, 12 cm thick LSPM-30 field coring mixture specimens were selected for testing. In order to eliminate the influence of other factors, three different gradation LSPM-30 mixtures were selected, and 9 samples were taken for each gradation.

![Figure 4. Core sample obtained on site](image)

Three groups of specimens were cut on one side and two sides respectively, and the cutting height was 3cm. The third group selected three specimens without cutting as control. The void ratio of the specimen is obtained by calculation method, and the actual porosity is calculated according to the fitting formula in the previous section, and the average porosity is obtained as follows.
Table 2. Porosity of different treatment methods before and after fitting calculation

| Calculation method | calculation method (%) | after modification of fitting formula (%) |
|--------------------|------------------------|------------------------------------------|
| Treatment mode     | uncut                  | single side cutting                      | double side cutting |
|                    |                        | uncut                                    | single side cutting | double side cutting |
| Group 1            | /                      | 19.2                                     | 13.6                | /                    | 19.2                       | 16.7                       |
| Group 2            | /                      | 15.5                                     | 13.9                | /                    | 17.6                       | 16.9                       |
| Group 3            | 22.0                   | 20.2                                     | 14.1                | 20.2                 | 19.5                       | 17.0                       |
| Average            | 22.0                   | 18.3                                     | 13.9                | 20.2                 | 18.8                       | 16.9                       |

It can be seen from the above table that the voids of the three groups of specimens are subject to single-sided cutting, double-sided cutting and non cutting treatment. On the whole, there is a trend that the more the cutting surface is, the smaller the void ratio is. Under the condition that the mixture is evenly shaped, it can be considered that the core sample processed by double-sided cutting is closest to the actual void ratio of the mixture. Therefore, the surface porosity of the mixture has an impact on the determination of the mixture porosity. The influence of 3cm mixture on the actual void of mixture is 0.7% ~ 2.6%, and the average value is about 1.7%. The specific value is affected by the mixture gradation and other factors.

According to the above results, it can be calculated that the average void of the mixture within the range of 3cm above and below the test piece is 23.7%, which is 6.8% larger than that of the core sample. This part of void ratio difference is mainly caused by the surface layer of the specimen, which is determined by the structural characteristics of the LSPM. The outer surface of field coring also belongs to the cutting surface, so the key to control on-site void is the difference between laboratory core sample and field core.

5.2. Calculation of void fraction difference between laboratory core and field core

The LSPM specimen is compacted by rotary compactor or large Marshall compaction in laboratory, so each surface of the specimen is in contact with the rigid mold, and there is no extrusion process between aggregates, and the surface is rough. On the other hand, the outer surface of the on-site coring mixture is cut by the coring machine, and the process of embedding and extruding between the aggregates has been completed, and the surface is smooth and dense. Only the connected gap is formed due to the structural characteristics of LSPM. The upper surface is formed by vibration compaction of steel wheel roller, which can basically be regarded as rigid surface contact, and the lower surface is generally semi-rigid base formed by cement stabilized materials. Therefore, the difference of void ratio between laboratory core and field core is mainly the difference between laboratory core and field core.

Since the maximum nominal particle size of LSPM-30 is 30mm, the influence range of surface void fraction should be less than or equal to 30mm. The results show that the average void fraction of the mixture within 3 cm of the specimen surface is 24.5%. Considering the cylindrical size effect, the void fraction parameters of the specimen can be obtained as follows.

Table 3. Calculation of void ratio between laboratory core and field core

| surface porosity about 30mm | the internal void | the total volume of the specimen | the void fraction of the laboratory formed specimen | the void fraction of field taken sample |
|-----------------------------|-------------------|---------------------------------|-----------------------------------------------|---------------------------------------|
| 23.7%                       | 16.9%             | 2120.6 cm³                      | 22.5%                                         | 20.2%                                 |

According to the data in Table 2, when the actual void of the test piece is 16.9%, the corresponding void ratio of the field core sample and the laboratory formed sample is 20.3% and 22.5%, respectively, and the difference between the void fraction of the field core sample and the laboratory formed sample is 2.2%.

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5.3. Porosity control of field and laboratory core samples

According to the above calculation, due to the large proportion of coarse aggregate and large void ratio of LSPM, there will be a large deviation between the porosity of LSPM specimen in laboratory molding test piece and in-situ core sampling sample and the actual void ratio inside the mixture. In order to ensure the quality of indoor mixture design and on-site mixture production, the research group considers that the void ratio of laboratory molding specimens should be controlled at 17.3% ~ 23.9%, and that of field core samples should be controlled at 15.6% ~ 21.6%, so as to control the actual void fraction in the mixture within the range of 13% ~ 18%.

| Internal porosity of specimen | Surface porosity of 30mm | Porosity of laboratory formed specimens | the void fraction of field taken sample |
|-------------------------------|--------------------------|----------------------------------------|---------------------------------------|
| 13%                           | 18.2%                    | 17.3%                                  | 15.6%                                 |
| 18%                           | 25.2%                    | 23.9%                                  | 21.6%                                 |

6. Conclusion

On the basis of raw material testing and LSPM-30 mixture proportion design, the volume index of LSPM based on calculation method and core Lok method is compared and analyzed in this paper. According to the field core sample test and porosity calculation, the control requirements of on-site and laboratory core sample porosity are proposed.

(1) For double-sided cutting core samples, when the porosity of core samples measured by calculation method is within 8.5 ~ 15%, the corresponding porosity of Corelock method should be controlled within 13 ~ 18%, which means that when the porosity of core sample calculated by calculation method is more than 15.5%, the approximate rate has insufficient compactness, and then there is the risk of insufficient high temperature stability.

(2) Through the calculation of void of different treatment methods of core samples, it is found that the surface mixture lacks the intercalation effect between aggregates, and the porosity of 3cm mixture in the surface layer is larger than that in the mixture. When the porosity measured by Corelock method is 16.9%, the average porosity of the surface 3cm mixture is about 23.7%.

(3) The results show that the porosity of core sample in laboratory is higher than that of in-situ core sample. When the porosity measured by Corelock method is 16.9%, the void fraction of in-situ core sample and laboratory molding sample are 20.3% and 22.5%, respectively, and the difference between them is about 2.2%.

(4) For LSPM-30, in order to ensure the quality of LSPM, the internal porosity of the test piece should be appropriate. The porosity of the laboratory molding specimen should be controlled at 17.3% ~ 23.9%, and the porosity of the core sample should be controlled in the range of 15.6% ~ 21.6%.

Reference:
[1] Technical specification for application of large size permeable asphalt mixture [S]. Local standard of Shandong Province. DB37/t1161-2009
[2] Test specification for asphalt and asphalt mixture of highway engineering [S]. Industrial standard of the people's Republic of China. JTG e20-2011, people's Communications Press. 2011
[3] Zhou Haifang. Performance evaluation of large size permeable asphalt mixture with different binders [D]. Shandong University, 2010