

# Internal Damage Mechanism of Permeable Asphalt Mixture by the Freeze-thaw Splitting

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**ABSTRACT.** The splitting strength of the permeable asphalt mixture before and after freeze-thaw cycles was obtained by freeze-thaw splitting test. And the CT scanning images of the specimen in different layers before and after freeze-thaw splitting was obtained. The micro-structures damage characteristics of the permeable asphalt mixture after freeze-thaw splitting was analyzed, and the evolution law of the inner micro-structures of the permeable asphalt mixture was analyzed by the damage variable. The results of this paper show that with the increasing number of freeze-thaw cycles, the splitting strength of the asphalt mixture decreases gradually. Most of the cracks of the permeable asphalt mixture after freeze-thaw cycled occurred at the initial void density distribution of the specimen, and the spreading direction of the void is basically consistent with the direction of the initial void. The mechanical properties of asphalt mixtures are poor with larger voids, and the increasing of the damage variable with larger voids is more than that with less voids.

**KEYWORDS:** Permeable asphalt mixture; Freeze-thaw splitting; CT scanning images; Damage variable.

## 1. Introduction

The freeze-thaw effect has an important effect on the road performance of the asphalt mixture. When the water enters the asphalt mixture through the surface of the table, it will replace the asphalt film and reduce the interfacial adhesion of the asphalt mortar and the aggregate [1-3]. When the freeze-thaw cycle occurs, the change of water phase will lead to the asphalt mixture freeze-thaw damage, so that the road performance is reduced, resulting in early damage [4]. In the large gap asphalt mixture, the impact of water on its road performance is particularly prominent [5-7]. Using image scanning technique, and to investigate the internal structure of the asphalt mixture, the mixture Variation stress damage during the introduction of structural damage variable concept, design, and performance evaluation for the asphalt mixture is significant [8]. In this paper, the splitting

strength of large voids asphalt mixture under different freezing and thawing cycles was studied, and the internal voids were analyzed by CT scanning technique. The damage variables of different layers were calculated and analyzed Split form of development.

## 2. Experimental procedure

The OGFC-13 grade asphalt mixture was used for the test, and the gradation is shown in tables (Table 1). Specimen for the standard crushing method of the Marshall specimen. In the mixture, the asphalt is SBS modified asphalt, the coarse and fine aggregate are selected basalt, the asphalt ratio is determined by the Marshall test, the optimum aspect ratio is 5.0%, the mineral content is 5.5%, the measured porosity is 20.3 %.

*Table 1 OGFC-13 gradation*

Sieve aperture /mm	16	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
Passing rate /%	100	95	74	21	12	10	9	7.5	6	5

According to JTG E20-2011 “Highway Engineering Asphalt and Asphalt Mixture Test Code” in the T0729-2000 method for freeze-thaw splitting test. Freeze-thaw split test specimen forming double-sided 50 times. The samples were divided into two groups, each group of four, one in 25 °C water bath soaking 2h after the determination of its splitting strength RT1; another group first by T0717-1993 method for vacuum saturation, and vacuum 15min, and then Under the pressure of the specimen placed in the water for 0.5h; the test pieces were taken out into the plastic bag, add about 10mL of water, tie the bag and put it into the -18 °C refrigerator to keep the temperature 16h; And then placed in a constant temperature water tank at 60 °C for 24 hours. This process is a freeze-thaw cycle. The samples were subjected to freeze-thaw cycles and placed in a water bath at 25 °C for 2 h to determine the cleavage strength RT2. Calculate the ratio of RT1 and RT2, ie, the residual strength ratio TSR.

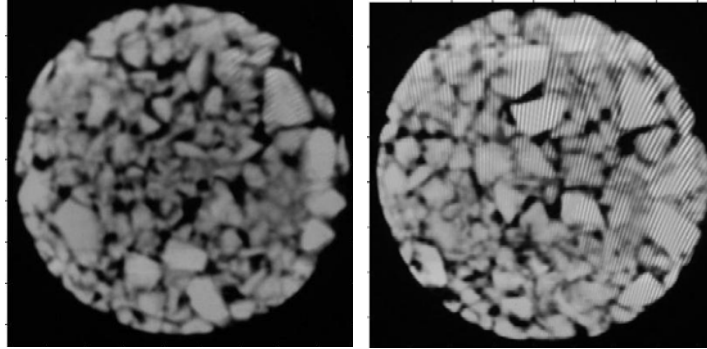
The specimens were scanned by the medical spiral CT machine (LightSpeed Ultra SYS) before and after freezing and thawing, and the CT scanning parameters were shown in tables (Table 2).

*Table 2 CT scan parameters*

Voltage /kV	Current /mA	Pitch	Amplification factor	Rotation time /s	Thickness /mm
120	210	0.875	5.0	0.8	5

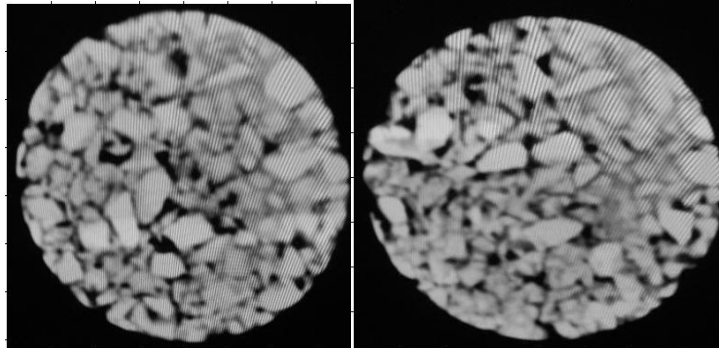
When scanning the specimen, the final crushed surface of the last 1 stamping surface will be taken as the top surface, and 12 scanning horizons are selected from the distance of 4.1mm from the top surface. The scanning interval is 5mm. And then

use the MATLAB software to obtain the CT scan image gray value processing, so that each layer of the gap between the gap and the measured porosity equal. And the actual void ratio of each scanning horizon is calculated by determining the value of the gray scale value.



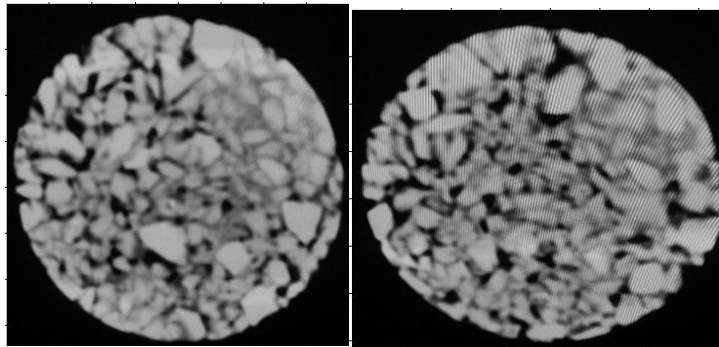
(a)4.1mm to the top

(b)9.1mm to the top



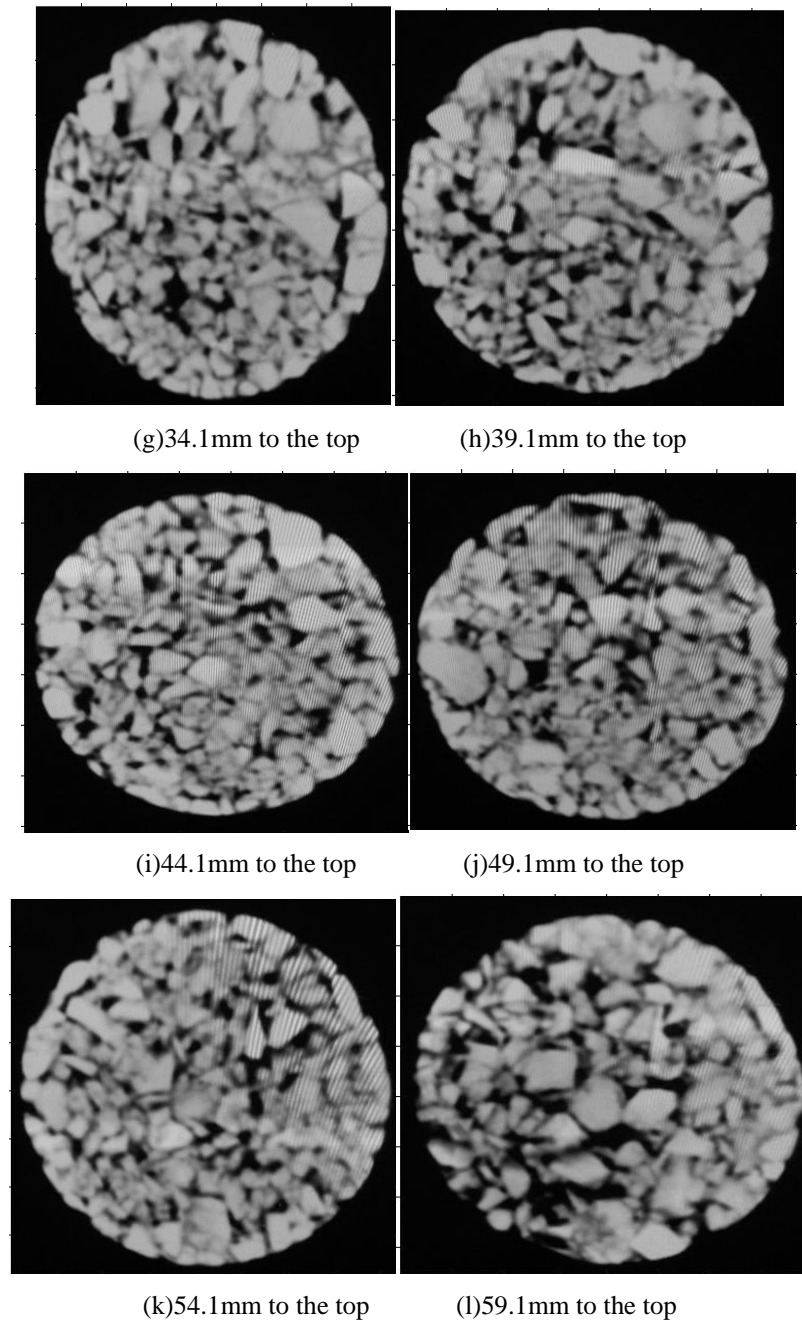
(c)14.1mm to the top

(d)19.1mm to the top



(e)24.1mm to the top

(f)29.1mm to the top



*Fig.1 Scanning of gray images with different depth CT scans*

Using the bimodal method [9-11] to digitize the scanned image and determine that the gray value of the image is larger than 108, and the gray value is less than 86. The gray value is between 86 and 108 between the parts for the asphalt mortar [12-14]. CT scan image in MATLAB in the gray image shown in figures (Fig. 1).

### 3. Test results and analysis

The shear strength of the specimen was determined by the number of times of freezing and thawing cycles, and the residual strength ratio was obtained. The test results are shown in tables (Table 3).

*Table 3 Different freezing and thawing cycles of the number of times under the specimen splitting strength*

The number of times of freeze-thaw cycles	Splitting strength /MPa	Residual strength ratio /%
0	0.78	100
1	0.69	87.99
2	0.63	80.72
3	0.58	74.2

It can be seen from tables (Table 3), after freezing and thawing cycle, the specimen splitting strength was significantly reduced, after freezing and thawing cycle of the specimen and not through the freeze-thaw cycle of the sample, after a freeze-thaw cycle, the split And the cleavage strength decreased by about 19% after two freeze-thaw cycles. After three freeze-thaw cycles, the cleavage strength decreased by about 26%. The experimental results show that the porosity of the large-gap asphalt concrete is large, and during the freezing-thawing cycle, the water enters the inside of the mixture and the mixture is destroyed, thus reducing the splitting strength of the specimen.

The void fraction of the different scanning horizons and the percentage of the area of the coarse aggregate in the cross section of the specimen are shown in figure. It can be seen from figures (Fig. 2), the initial state of the specimen, asphalt mortar and coarse aggregate distribution is not uniform, coarse aggregate and more local distribution of the gap, asphalt slurry corresponding distribution less. The CT image voidage distribution of the specimen after 1 freeze-thaw cycle and splitting test is shown in figures (Fig. 2).

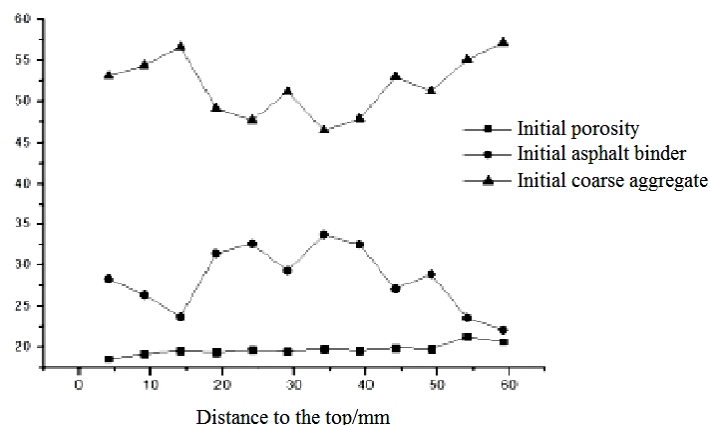


Fig. 2 Porosity, asphalt binder and coarse aggregate area percentage

It can be seen from figures (Fig. 3), the specimen after freeze-thaw split, the gap at all levels generally increased, but the increase was significantly different: the initial porosity greater porosity increases, the initial porosity is small The increase is not obvious; splitting damage occurred in the initial porosity of the specimen. It can be seen that the formation and development of fractures are closely related to the initial void distribution of the specimen.

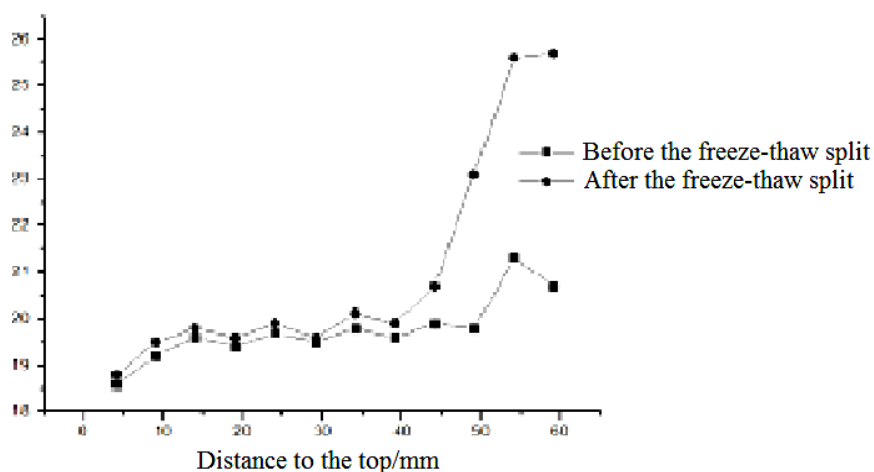


Fig.3 Freeze-thaw split before and after each layer of porosity

#### 4. Study on Freeze - thaw Damage of Specimen

In order to quantitatively analyze the internal damage of large voids asphalt

mixture, this paper introduces the following mathematical models and assumptions [15]:

- (a) Asphalt mixture specimen internal damage for the same type of damage, the specific form of small holes;
- (b) Holes are randomly distributed in the specimen;
- (c) the area of individual holes in each resolution unit is substantially equal and recorded as;
- (d) the number of damaged holes in the cross-body domain independent of each other;
- (e) that the probability of the existence of a hole in the center of the center is only related to, and not constant 1;

- (f) There are limited holes in the body domain,  $\sum_{k=0}^{\infty} P_k(X) = 1$  ;
- (g) The probability that more than one hole is present in the body domain is the high order infinitesimal as shown in equation (1).

$$\lim_{X \rightarrow 0} (1 - P_0(X) - P_1(X)) / X = 0 \quad (1)$$

Based on the distribution characteristics of the internal damage of the asphalt mixture and the above assumptions [13-14], this paper uses the Poisson distribution to derive the damage variables before and after the freezing and thawing of the asphalt mixture. Assuming that the CT scanning resolution unit area is, then the probability of the number of voids in the body domain is:

$$P(n=k) = \frac{(\lambda A)^k}{k!} \exp(-\lambda A) \quad (2)$$

In the formula,  $\lambda$  is the mathematical expectation of the number of voids per unit area.

Assuming that there is no damage to the matrix large voids asphalt mixture, the density of the specimen is, the number of voids is, then the average density distribution of the asphalt mixture in the resolving unit is:

$$\rho = \rho_0 \left( 1 - n \times \frac{A_0}{A} \right) \quad (3)$$

From the formula (3) asphalt mixture test specimen density  $E(\rho)$  and variance  $D(\rho)$  can be obtained

$$E(\rho) = \rho_0(1 - \lambda \times A_0) \quad (4)$$

$$D(\rho) = \rho_0^2 \times \frac{A_0^2}{A} \times \lambda \quad (5)$$

According to equation (4) can be further obtained within the same resolution unit damage gap area, as shown in equation (5):

$$A_0 = \frac{D(\rho) \times A}{\rho_0 \times [\rho_0 - E(\rho)]} \quad (6)$$

$$\lambda = \frac{[\rho_0 - E(\rho)]^2}{D(\rho) \times A} \quad (7)$$

According to the definition of the damage variable [15], the damage variable on the scanning section can be calculated according to equation (6).

$$D_m = \frac{S - S_{ef}}{S} = \frac{S_d}{S} = \frac{n \times \lambda \times A_0}{S} \quad (8)$$

In the formula, for the scanning cross-sectional area of the damage variable; for the specimen scanning cross-sectional area; for the specimen scanning cross-section effective area; for the specimen scanning cross-section damage area.

CT device resolution is  $m_0$ , then  $n = S / m_0^2$ , then equation (6) can be written as:

$$D_m = \frac{1}{m_0^2} \lambda A_0 = \frac{1}{m_0^2} \left[ 1 - \frac{E(\rho)}{\rho_0} \right] \quad (9)$$

## 5. Conclusion

With the increase of the number of freeze - thaw cycles, the splitting strength of asphalt mixture specimen is obviously reduced. Water into the specimen after the internal, will destroy the asphalt mortar and aggregate interface adhesion, the number of freeze-thaw cycles increased, the more the role of water, the more obvious damage.

When the asphalt mixture is cracked and broken, the cracks are mostly formed at the initial porosity of the specimen. The development direction of the fracture is basically the same as the direction of the initial gapp. It can be seen that the formation and development of the fracture and the initial void The distribution of the state is closely related.



The mechanical properties of the asphalt mixture specimen are poor, and when the damage occurs under external force, the internal damage is formed, and the position and direction of development are closely related to the initial void distribution.

The internal damage variable of the asphalt mixture specimen is related to the initial porosity of the specimen. The damage ratio of the initial porosity is larger than that of the stratosphere with small porosity.

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