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Effect of volumetric properties on indirect tensile strength and cracking tolerance index of cored asphalt pavement

아스팔트 포장의 부피 특성이 간접인장강도 및 피로균열 지수에 미치는 영향분석

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ABSTRACT

PURPOSES : The aim of this study is to evaluate the effects of air voids, binder content, and aggregate gradation on the indirect tensile strength (IDT) and cracking tolerance index (CT_{index}) of cored asphalt pavements.

METHODS : Cored samples were obtained from roads in Incheon city, and several laboratory experiments were performed. First, the cored samples were first to cut into a size appropriate for the IDT test. Subsequently, the air voids of the samples were measured. The damaged sample from the IDT test was loose mixed at 150 ℃ before the binder content was determined, which was conducted via an asphalt extraction test. Finally, the clean aggregates obtained from asphalt extraction process were analyzed in the aggregate gradation test.

RESULTS : The result shows that an increase in air voids from 4% to 8% decreases the IDT and cracking tolerance index (CT_{index}) by 30% and 28%, respectively. Incorporating a binder enhances the ductile behavior of the asphalt mixture, resulting in a higher CT_{index}. Finally, the contribution of the aggregate grade on the IDT and CT_{index} is negligible.

CONCLUSIONS : The IDT and CT_{index} are primarily affected by the air voids and binder content. A higher percentage of air voids results in a lower IDT. In addition, a higher amount of binder increases the IDT and CT_{index} of the cored samples. Meanwhile, the aggregate grade does not affect the IDT.

Keywords
Cored asphalt mixture, air voids, indirect tensile strength, CT_{index}, asphalt extraction, aggregate gradation

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1. Introductuon

1.1. Literature review

During service life, asphalt pavement is subjected to repetitive loads as well as environmental conditions (Fernández-Gómez et al., 2013). One of the most deterior -ations of asphalt pavement is the decrease in bearing loads–indirect tensile strength of asphalt mixture(Apeagyei, 2011).

Many methods have been developed to improve the indirect tensile strength of the asphalt mixture. For example, Phan et al. introduced coated aramid fiber to improve the indirect tensile strength of the asphalt mixture (Phan, Nguyen, et al., 2021). At low temperatures, Phan et al. used micro-encapsulated phase change materials to improve the low-temperature indirect tensile strength test of asphalt mixture (Phan et al., 2022; Phan, Park, et al., 2021). Although improving the indirect tensile strength of asphalt mixture has been focused in on recent years, there is a lack of the result on the evaluation indirect tensile strength of asphalt pavement during pavement's service life. In addition, the effect of air voids, binder content, and aggregates on indirect tensile strength is also a hot topic that attracts many researchers. As known that one of the simplest asphalt mixture tests to provide an indicator of mixture resistance to the critical form of pavement distresses, the indirect tensile (IDT) strength test is mainly used in laboratory conditions (KS-F-2382, 2017). In recent years, Fujie et al. introduced the indirect tensile asphalt cracking test (IDEAL-CT) to reflect the cracking resistance of asphalt mixture by using CT_{index} (Zhou et al., 2017).

1.2. Research contents

This study aims to evaluate the effect of air voids, binder content, and aggregate gradation on cored asphalt mixture's indirect tensile strength and cracking tolerance index. The cored samples were collected from roads in Incheon city. The air voids of cored samples were firstly determined, then the indirect tensile strength test and indirect tensile asphalt cracking test (IDEAL-CT) were employed to measure the IDT and CT_{index}. After the loose mix process, the damaged sample was measured for binder content and aggregate gradation.

2. Test method

2.1 Sample collection and preparation

In this experiment, samples were collected on serval roads in Incheon city. At each location, at least two samples were collected. A cored sample includes 2, 3, or 4 layers, coressponding to top, middle, and bottom layer. After collection, the cored samples are cut into the size of the indirect tensile strength test specification. The cut-off machine with a maximum cutting diameter of 150 mm was employed to cut cored sample. Due to the different maximum gradation sizes of each layer, the sample size of the first and second layers are 50 mm in thickness, while the third and fourth layers are 70 mm in thickness Figure 1.

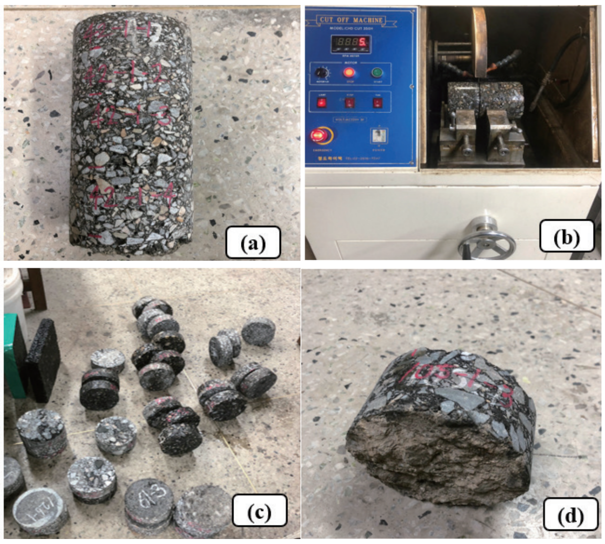

Fig. 1 Cutting process of cored sample

- (a) Cored sample
- (b) Cut off machine with the maximum cutting-diameter of 150 mm.
- (c) After cutting, the samples are condition at 25 ℃ for 48 hours.
- (d) The final sample.

2.2. Air void test

This test aims to measure the air voids of the asphalt sample. The test process follows KS-F 2495 standard (KS-F-2495, 2017). Due to these samples being collected from roads, the bulk specific gravity (G_{mb}) was firstly measured after the cutting process, as shown in Figure 2. Then, these samples were dried at room condition for at least 48 hours before conducting indirect tensile strength. Afterward, the damaged sample was loosed mix at 150 °C and determined the theoretical specific gravity (G_{mm}) was determined as shown in Figure 2. The asphalt loose mix process is displayed in Figure 3. The calculations of air voids, G_{mb}, G_{mm} are displayed in equations (1), (2), and (3), respectively.

Fig. 2 Air voids measurement test

- (a) Measure mass of sample at the dry, submerged, and SSD conditions.
- (b) Aggregate is separated into particles smaller than 0.25 inches.

Fig. 3 The damaged samples from indirect tensile strength test were loosed mix at 150 ℃ for 6 hours.

$$AV = \left(1 - \frac{G_{mb}}{Gmm}\right) \times 100 \tag{1}$$

Where:

- G_{mb}: bulk specific gravity
- G_{mm}: theoretical maximum specific gravity

$$G_{mb} = \frac{A}{B - C} \tag{2}$$

Where:

- A: mass of sample in the air (gram),
- B: mass of saturated surface dry sample in the air (gram),
- C: mass of sample in water (gram).

$$G_{mm} = \frac{A}{A + D - E} \tag{3}$$

Where,

- G_{mm}: theoretical maximum specific gravity,
- A: sample mass in the air (gram),
- D: mass of container filled with water (gram),
- E: mass of container and sample filled with water (gram).

2.3. Indirect tensile strength test

This test was conducted to measure the indirect tensile strength of the asphalt sample. The test is carried out in compliance with KS-F 2382 standard (KS-F-2382, 2017). The Dynamic Testing System 30 kN (DTS-30) was employed to conduct an indirect tensile strength test (Figure 4). This test was conducted at 25 ℃. Run an indirect tension test on each sample by placing the sample between the two bearing plates in the testing machine and applying the load at a constant rate of 50.8 mm/minute. During the testing process, the load and displacement were recorded. The asphalt sample's indirect tensile strength (S_t) is calculated by equation (4).

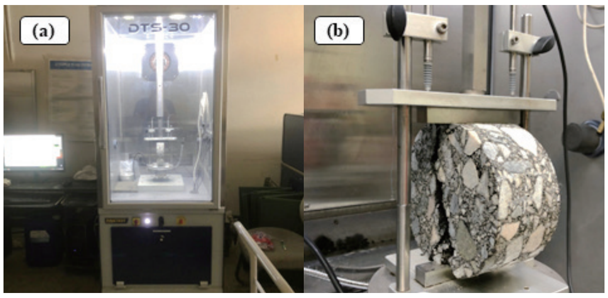

Fig. 4 DTS-30 machine, and test setup

- (a) Dynamic Testing System 30 kN (DTS-30)
- (b) The tested sample

$$S_t = \frac{2 \times P}{Dt} \tag{4}$$

Where:

- S_t: indirect tensile strength (MPa),
- P: peak load (kN),
- D: diameter of sample (mm),
- t: thickness of the sample (mm).

2.4. Indirect tensile asphalt cracking test (IDEAL-CT)

The IDEAL-CT aims to determine the cracking potential of asphalt mixtures with a fracture mechanics-based parameter named the Cracking Tolerance index (CT_{Index}) (Zhou et al., 2017). Asphalt mixture specimens have a diameter of 150 mm. Temperature is maintained at 25 ℃ for at least two hours. The test was conducted with a monotonic loading rate of 50 mm/minute cross-headed displacement. The calculation of CT_{index} is shown in equation (5). In this equation, CT_{index} was computed based on the slope at 75% post-peak load, fracture energy, displacement at 75% post-peak load, and diameter of the sample. The larger the CT_{index} indicated, the better in cracking resistance. During the test, the load displacement was recorded and used to compute

CT_{index}. To efficiently compute process, a computer program named IDEAL-CT Calculator was developed based on Python programing language. The inputs for this program are load and displacement, and the outputs are CT_{index}, peak load, and fracture energy, as shown in Figure 5.

$$CT_{Index} = \frac{G_f}{|m_{75}|} \times \left(\frac{l_{75}}{D}\right)$$
$$m = \left|\frac{P_{85} - P_{65}}{l_{85} - l_{65}}\right| \tag{5}$$

Where:

- Gf: fracture energy (J/mm^2),
- m_{75}: a slope at 75% post-peak load,
- P_{65}, P_{75}, P_{85}: load at 65%, 75%, 85% post-peak load(kN).
- l_{65}, l_{75}, l_{85}: displacement at 65%, 75%, 85% post-peak load (mm)

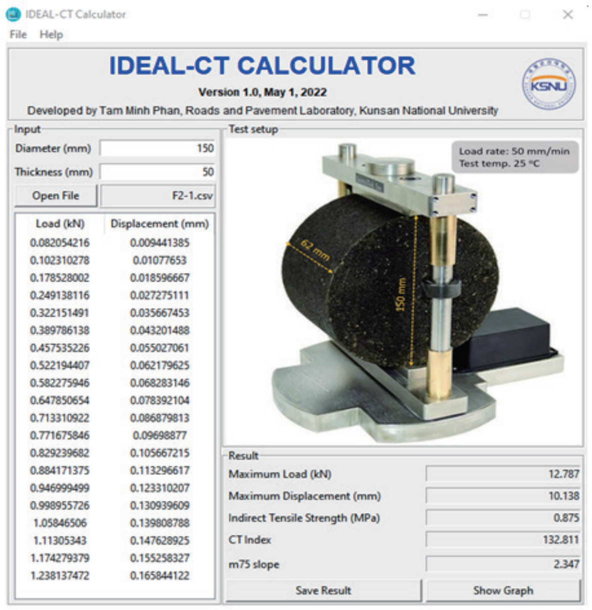

Fig. 5 IDEAL-CT Calculator program for calculating the CTindex based on the load-displacement

2.5. Measurement of asphalt binder content

After the loose mix process, the asphalt mixture was used to measure the binder content. The test follows KS-F 2354 standard (KS-F-2354, 2018)*KS-F 2354 (Standard test method for asphalt content from asphalt paving mixtures). Firstly, a 1500-gram asphalt mixture was mixed with 400 ml Trichloroethylene (TCE) and placed in an extraction machine at 150 °C for 90 minutes to remove the binder from the aggregates, as shown in Figure 6. Then, the binder-TCE solution and clean aggregates were collected. To improve the accuracy of binder content, small dust is removed using centrifugation. The binder-TCE solution is centrifugated at 3600 rotations per minute for 10 minutes to remove small dust. The recovery of asphalt solution by abson was used to remove the TCE from the binder-TCE solution. The solution was poured into the 1000 ml flask, as shown in Figure 6. When the temperature reached 135°C, carbon dioxide (CO_2) was supplied at 100 ml/min, and when the temperature reached 157 °C, the CO_2 was 900 ml/min. After completely removing TCE, measure the weight of the binder and flask. The binder was stored in the centrifuge tube. The binder content was calculated by the equation:

$$P_b = \frac{W_{bf} - W_f}{W_m} \times 100 \tag{6}$$

Where:

- P_b: binder content of asphalt mixture (%),
- W_{bf}: weight of binder and flask (gram),
- W_f: weight of flask (gram),
- W_m: weight of asphalt mixture (gram).

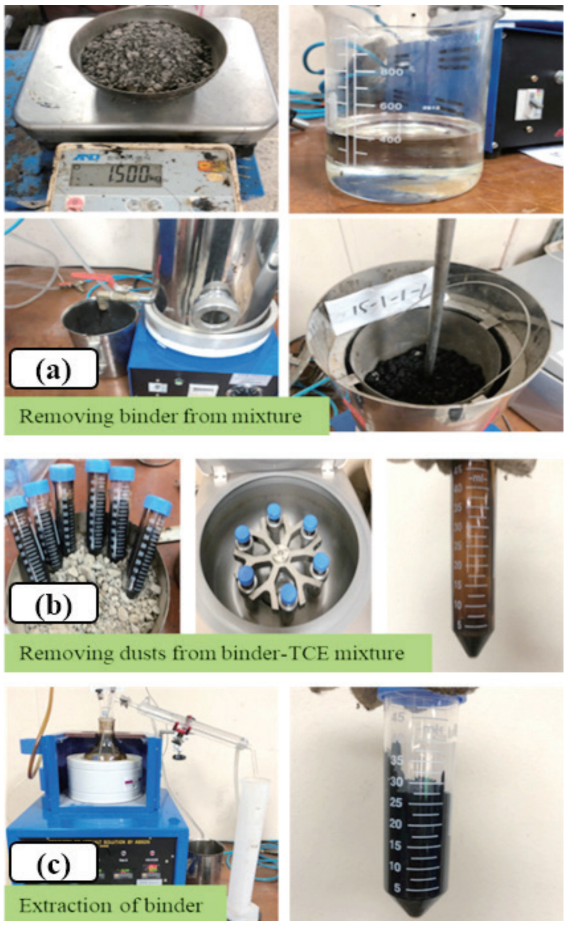

Fig. 6 Asphalt extraction process

- (a) Asphalt mixture was mixed with 400 ml Trichloroethylene (TCE) placed in extraction machine to remove the binder from the aggregates.
- (b) The binder-TCE solution are centrifugated at 3600 rotation per minute for 10 minutes to remove small dusts.
- (c) The recovery of asphalt solution by abson.

2.6. Aggregate gradation test

This test aims to determine the size gradation of asphalt mix as well as the Nominal maximum aggregate size. The clean aggregates obtained from the asphalt extraction process were dried in the oven at 110 ℃ for 4 hours to remove moisture prior to the gradation test. The test follows KS-F 2502 standard (KS-F-2502, 2019):

- Sieves were assembled in order to decrease the size of the opening from top to bottom and placed the nest of sieves was over a pan.
- The mass of the material retained on each sieve size was measured.
- The mass retained on a specific sieve size and the mass retained on all sieves with larger openings were recorded.

Fig. 7 Aggregate gradation test

3. Results-discussion

3.1. Effect of air void

Figure 8 shows the effect of air voids on the indirect tensile strength of the asphalt mixture. The increase in the percent of air void could decrease indirect tensile strength. In addition, the air void of the first and second layers which were 4% to 6%, compared to 8-10% of the third and fourth layers. Lower air voids may increase the interlocking between aggregates, which leads to higher indirect tensile strength. The IDT of the first and second layers ranged from 0.6 to 1.2 MPa, while that of the third and fourth layers were 0.5-1.0 MPa. The effect of air voids on the CT_{index} of the asphalt mixture is also shown in Figure 8. In general, asphalt mixtures with lower air voids acquired a higher CT_{index}, especially the first and second layers gained the highest CT_{index}. This behavior was similar to the trend of indirect tensile strength. In other words, air voids content plays a vital role in the cracking resistance of asphalt mixture.

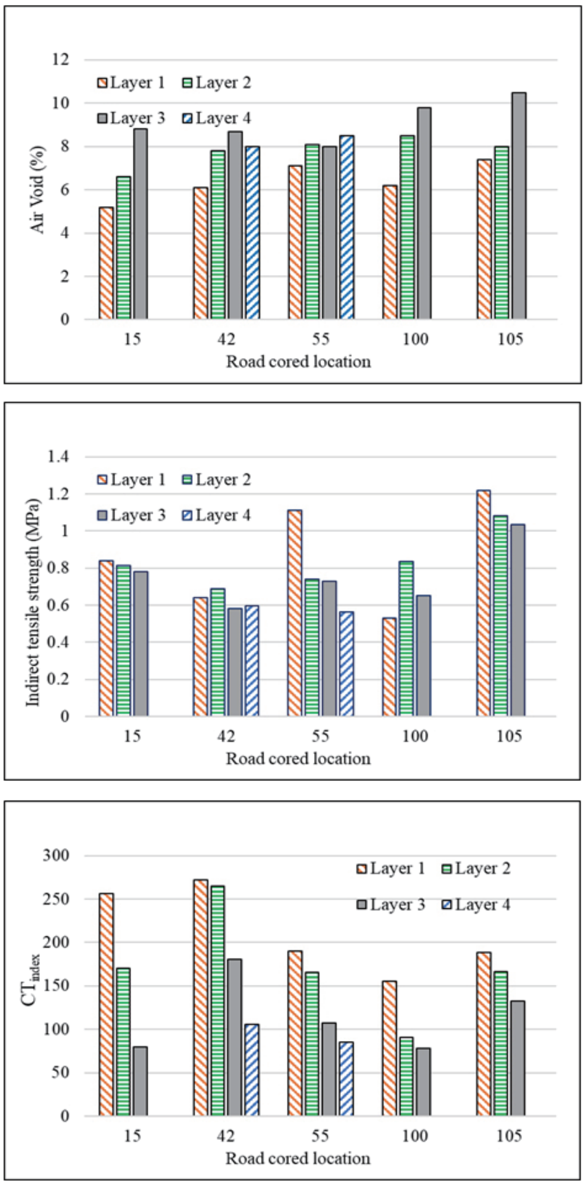

Fig. 8 Effect of air void on ITS and CT_{index}

3.2. Effect of binder content

The binder contents of cored asphalt sample are shown in Figure 9. The first and second layers generally showed a higher binder content than the third and fourth layers. The binder content ranged from 3.2% to 4.6%. Asphalt mixture with higher binder content acquired a larger indirect tensile strength. For example, the indirect tensile strength of the first layer - sample 15 was 0.81 MPa, corresponding to 4.5% binder content.

Meanwhile, the first layer of sample 42 was 0.63 MPa with a binder content of 4.1%. The effect of asphalt binder on CT_{index} was more clearly, as shown in Figure 9. The higher binder content could improve the ductile behavior of the asphalt mixture, resulting in a higher CT_{index}. The binder can explain this could improve the adhesion between aggregates, due to the suitable amount of asphalt required to cover all particles without weak voids.

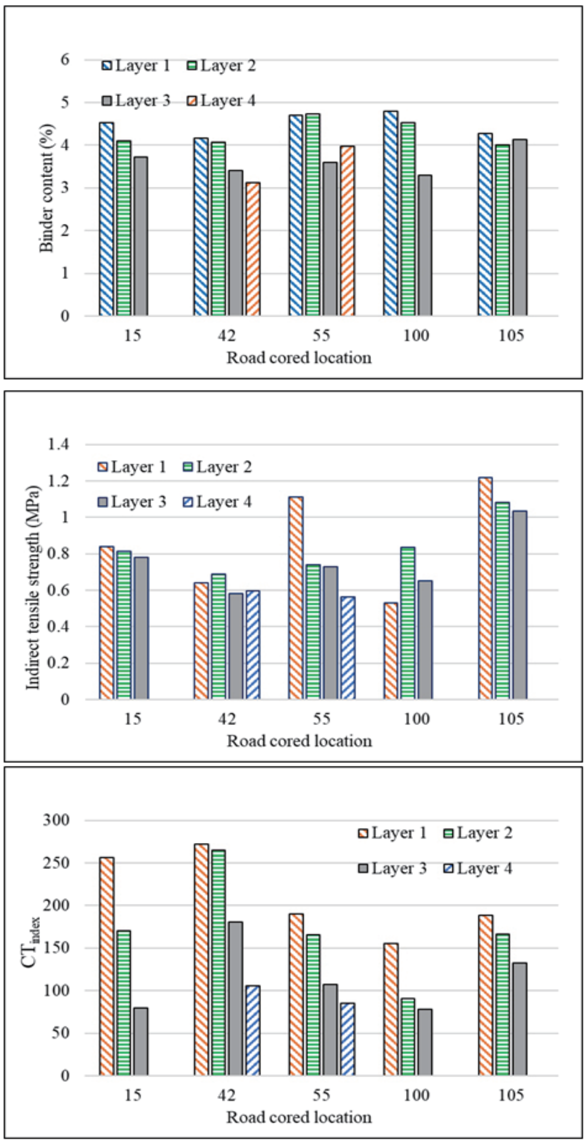

Fig. 9 Effect of binder content on ITS and CT_{index}

3.3. Effect of aggregate gradation

The aggregate size gradation and nominal maximum aggregate size are shown in Figure 10. Overall, the aggregate of the first and second layers was smaller than that of the third and fourth layers. Considering to indirect tensile strength, the aggregate size gradation lightly contributed to IDT. The IDT of 9.5 and 12.5 mm nominal maximum aggregates were not much different. Similarly, the effect of aggregate gradation on the CT_{index} was not clear.

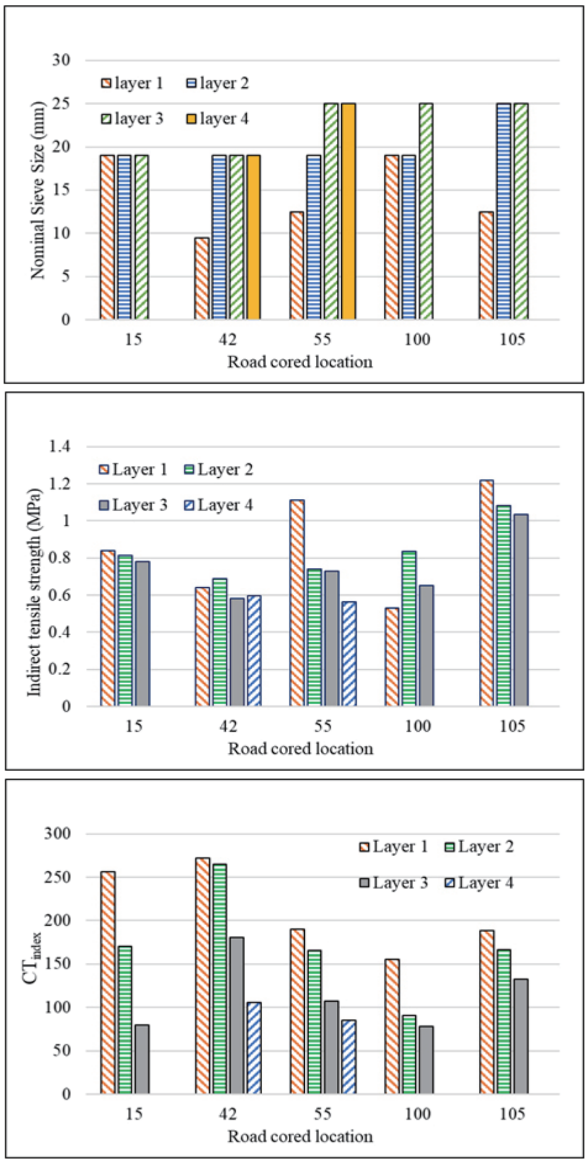

Fig. 10 Effect of aggregate gradation on ITS and CT_{index}

4. Conclusions

This study aims to evaluate the effect of air voids, binder content, and aggregate gradation on indirect tensile strength and CT_{index} of cored asphalt samples. Several key findings from this study are drawn below:

- Air voids content plays an essential role in the indirect tensile strength and the cracking tolerance index of asphalt mixture. The higher air voids content leads to lower IDT and CT_{index} as well.
- The effect of binder content obviously contributed to

the CT_{index} of the asphalt mixture. This is because of the enhancement of ductile behavior. In addition, higher binder content leads to greater indirect tensile strength.

- The contribution of aggregate size gradation (Nominal maximum aggregate size) on the indirect tensile strength and CTindex was not clearly. The larger aggregate size could lightly increase indirect tensile strength.

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