Design Method and Evaluation Criteria on Gyratory Compaction Based Cold-Mixed and Cold-Laid Recycled Asphalt Mixture

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Abstract. Cold-mixed recycled asphalt mixture is widely used due to the advantages of good eco-friendliness, resource conservation, and convenient construction. In order to further improve the mixing ratio design theory of cold-mixed recycled mixture, this paper has presented the research on design method and evaluation criteria of cold-mixed and cold-laid recycled asphalt mixture based on gyratory compaction. Research has shown that fine aggregate and mineral powder adhere to asphalt and exist in the form of agglomeration in the Reclaim Asphalt Pavement (RAP), which will cause the gradation of the milling plan material to decay after extraction. According to the viscosity characteristics of cold mixed asphalt, it is recommended that the mixing temperature of the mixture should be greater than 25℃, the compaction of cold-mixed recycled mixtures is easier to achieve by using gyratory compaction method. The paper proposes a test method to determine the optimal asphalt content based on initial strength and sweep test, and proposes a test method for controlling the strength of the mixture by the number of compactions and the forming temperature, establishes evaluation system of initial strength and final strength of cold-mixed recycled mixture, and corrects the evaluation method of high temperature stability and water stability of cold-mixed recycled mixture. The results show that the cold-mixed recycled mixture has low initial strength, insufficient high-temperature stability and water stability. With the volatilization of the diluent, the strength, high temperature stability and water stability of the mixture have been significantly improved.

Keywords: Cold-mixed and cold-laid mixture, milling material, gyratory compaction method, the mix proportion design, performance evaluation.

1. Introduction

With the rapid development of highway transportation in China, the total kilometers of newly constructed highways has reached new highs repeatedly, and the shortage of stone resources has become a critical issue that limits the development of highway transportation in China. In addition, the traditional hot-mixed asphalt mixture is contrary to the concept of "green transportation" proposed by China, due to its many disadvantageous factors such as high construction temperature, serious waste of...
resources, and short construction season. The cold-mixed recycled asphalt mixture realizes the combination of cold-mixed technology and recycling technology. Mixing and construction under normal temperature conditions have the unique advantages of low cost, less pollution, saving resources, protecting the environment, and extending the construction season. In the new era of "resource-saving society" promoted by the country, it has broad application prospects.

According to the different cementitious materials, cold-mixed recycled mixture can be categorized into three types: emulsified cold-mixed recycled mixture, solvent-based cold-mixed recycled mixture, and reactive cold-mixed recycled mixture [1-2]. Other countries have begun research on cold-mixed recycled mixture since the 1950s and 1960s, UK and France [3] mainly used emulsified cold-mixed recycled mixture, and developed different types of emulsified asphalt according to different purpose of usage; Finland [4-5] have researched on the technology of solvent-based cold-mixed recycled mixture, and several test roads were paved with good application results. After long-term research in Japan and Australia [6], a complete system for the design and construction of reactive cold-mixed recycled materials was formed. In China [7-8], research on the strength formation mechanism of cold-mixed recycled mixtures and the composition design of cold-mixed recycled mixtures have been conducted based on the experience learned from other countries.

In China, the Marshall compaction method is still the main design method for the mix proportion design of cold-mixed recycled mixtures. But research shows that when the mixture contains a large amount of milling material, the mixture is easy to rebound and difficult to compact. However, the gyratory compaction method imposes the vertical pressure and horizontal shear force to the test piece through the rubbing effect on the mixture, so that the mixture can more easily reach the required compaction degree, and has higher consistency with the actual road construction. Up till now, a systematic system for the application of the gyratory compaction design method in cold-mixed recycled asphalt mixtures has not been formed in our country. In this paper, the gyratory compaction method based mix proportion design and evaluation method of cold-mixed recycled asphalt mixtures are studied, which will guide the engineering application of compaction method in cold-mixed recycled mixture.

2. Technical Specifications of Raw Materials

2.1. Milling Material

The milling material used in this paper comes from a highway in Rizhao City. The original mixture gradation is AC-13. The milling material crushing screen is divided into three sizes: 10-15mm, 5-10mm, 0-5mm. Then aggregate screening test is performed for each milling material before and after extraction test. The test results are shown in Table 1.

| Screen size (mm) | 16 | 13.2 | 9.5 | 4.75 | 2.36 | 1.8 | 0.6 | 0.3 | 0.15 | 0.075 | Asphalt content |
|------------------|----|------|-----|------|------|-----|-----|-----|------|------|-----------------|
| RAP 10-15 before extraction | 100 | 75.3 | 19.7 | 9.7 | 3.7 | 2.1 | 1.3 | 0.3 | 0.2 | 0.3 | 3.0% |
| after extraction | 100 | 82.2 | 32.1 | 18.5 | 13.9 | 11.8 | 9.6 | 6.9 | 5.6 | 4.5 |
| RAP 5-10 before extraction | 100 | 100 | 82.3 | 17.8 | 7.8 | 2.3 | 1.3 | 0.7 | 0.3 | 0.3 | 4.4% |
| after extraction | 100 | 100 | 90.2 | 30.6 | 16.5 | 14.7 | 12.5 | 9.6 | 7.9 | 6.3 |
| RAP 0-5 before extraction | 100 | 100 | 100 | 97.3 | 53.4 | 42.3 | 37.9 | 22.8 | 18.7 | 12.3 | 7.0% |
| after extraction | 100 | 100 | 100 | 99.8 | 75.0 | 60.3 | 46.6 | 26.4 | 20.7 | 15.9 |
2.2. Gradation Design
According to the gradation requirements and milling materials screening results of our "Specifications for design of highway Asphalt Pavement" [9], the gradation design of cold-mixed recycled asphalt mixture is performed. The test results of gradation design are shown in Table 2.

| Screen size (mm) | 16  | 13.2 | 9.5 | 4.75 | 2.36 | 1.8  | 0.3  | 0.075 |
|------------------|-----|------|-----|------|------|------|------|-------|
| gradation after extraction | 100.0 | 96.4 | 83.5 | 62.8 | 45.2 | 36.9 | 17.5 | 10.7  |
| gradation before extraction | 100.0 | 95.1 | 78.6 | 55.9 | 29.8 | 22.3 | 11.7 | 6.3   |
| upper limit of gradation | 100 | 90  | 72  | 40   | 26   | 15   | 8    | 2     |
| lower limit of gradation | 100 | 90  | 72  | 40   | 26   | 15   | 8    | 2     |

By comparing and analyzing the gradation of the milling materials before and after the extraction, it is known that the gradation decay of the RAP material occurs after extraction, the coarse aggregate content in the mixture decreases, and the fine aggregate and mineral powder content increase. The main reason is that the fine aggregate and mineral powder in the milling materials are wrapped by asphalt to form a block or adhere to the coarse aggregate, which leads to the coarse gradation of the RAP mixture.

2.3. Asphalt
Research shows that [10-11] solvent-based cold-mixed recycled asphalt mixture has better mechanical properties. According to the "solvent and dissolution theory", the solvent-based asphalt used in this paper is the mixture of mainly 90# matrix asphalt, diluents and cold-mixed additives. The technical properties of 90# matrix asphalt are shown in Table 3.
According to the "Standard Test Methods of Bituminous Mixtures for Highway Engineering" [12], the relevant tests of asphalt technical properties were performed on the cold-mixed asphalt. The test results are shown in Table 4.

Table 3. Technical index of 90# matrix asphalt.

| Test items                          | unit | Test results | skills requirement |
|------------------------------------|------|--------------|--------------------|
| Applicable climate zone            |      | 1-3          | Class A | Class B |
| Penetration (25℃, 5s, 100g)        | 0.1mm| 88           | 80~100  | 80~100  |
| Penetration index PI               | /    | -1.3         | -1.5~+1.0         | -1.8~+1.0 |
| Softening Point                    | ℃    | 45           | ≥45    | ≥43     |
| 10℃ Ductility                      | cm   | >150         | ≥20    | ≥15     |
| 15℃ Ductility                      | cm   | >150         | ≥100   | ≥100    |
| Wax Content (Distillation)         | %    | 2.1          | ≤2.2   | ≤3.0    |
| Flash Point                        | ℃    | 290          | ≥245   | ≥245    |
| Solubility                         | %    | 99.79        | ≥99.5  | ≥99.5   |
| Density (15℃)                      | g/cm³| 1.010        | Measured record | Measured record |
| TFOT (163℃, 85min)                | %    | -0.04        | ≤±0.8  | ≤±0.8   |
| Residual penetration ratio         | %    | 85           | ≥57    | ≥54     |
| Residual ductility (10℃)           | cm   | 57           | ≥6     | ≥4      |

Table 4. Technical properties of cold mixed asphalt.

| Test items       | Flash Point (℃) | 25℃ Brookfield viscosity (Pa·s) | 225℃ Distillation residue | Penetration (0.1mm) | Softening Point (℃) | 15℃ Ductility (cm) | Mass loss (%) |
|------------------|-----------------|---------------------------------|---------------------------|---------------------|---------------------|-------------------|---------------|
| Test results     | 66              | 1.251                           |                            | 77                  | 48                  | >150              | 87.5          |

The Absen method is used to recycle the asphalt in the milling material. According to the estimated optimal amount of asphalt, add 1.5% of cold-mixed asphalt to the aged asphalt. Then compare the technical properties of asphalt recycled from the milling materials and "recycled asphalt + 1.5% cold-mixed asphalt", the test results are shown in Figure 2.
Comparing the changes in the technical properties of the recycled asphalt after adding the cold-mixed asphalt, it can be seen that the penetration value and ductility value of the recycled asphalt increase, and the softening point decreases. The asphalt pavement is affected by sunlight, natural environment and other factors during the service period, which causes asphalt aging. But the cold-mixed asphalt additive contains some regenerant, which has certain regeneration function. Adding cold-mixed asphalt has the effect of restoring the aged asphalt to its original performance.

2.4. Asphalt Adhesion
Cold-mixed asphalt is a liquid state at normal temperature and has low viscosity for good construction and workability. Good adhesion between the asphalt and the milling material is required to prevent the mixture from flaking and peeling. This paper has referenced China’s standard "Standard Test Methods of Bituminous Mixtures for Highway Engineering" to perform adhesion test of cold-mixed asphalt by using the boiling method.

![Figure 3. Adhesion Test of Cold-mixed Asphalt.](image)

**Table 5. Adhesion grade of asphalt and aggregate.**

| The peeling of asphalt film on the surface of stone after the test | Adhesion Grade |
|-------------------------------------------------|----------------|
| Asphalt membrane is completely preserved, the percentage of peeling area is close to 0 | 5 |
| A small part of the asphalt membrane is moved by water, the thickness is uneven, and the peeling area percentage is less than 10% | 4 |
| The bituminous film is obviously moved by water, and basically remains on the surface of the stone, and the peeling area percentage is less than 30% | 3 |
| Most of the bituminous membrane is moved by water and is partially retained on the surface of the stone material, and the peeling area percentage is greater than 30% | 2 |
| The asphalt membrane is completely moved by water, the stone is basically exposed, and the asphalt is completely floating on the water surface | 1 |

The study found that after the boiling process, part of the asphalt on the aggregate surface was moved by water, the thickness was uneven, and the spalling rate was less than 5%, it shows that the adhesion grade of cold mixed asphalt and milled material is 4.

The road construction using cold-mixed asphalt mixtures at normal temperature requires the cold-mixed asphalt to have a lower viscosity. This paper analyzes the change in cold-mixed asphalt viscosity with temperature through the Brookfield viscosity test. The test results are shown in Table 6.

**Table 6. Test results of Brookfield viscosity of cold mixed asphalt.**

| Temperature (°C) | 5    | 15   | 25    | 35    |
|-----------------|------|------|-------|-------|
| Viscosity (Pa·s) | 0.549| 0.354| 0.248 | 0.137 |
Figure 4. Brookfield Viscosity of Cold-mixed Asphalt.

It can be known from the above tests that when the temperature is low, the viscosity of the asphalt is higher, which is not conducive to the mixing and wrapping of the asphalt mixture. As the temperature rises, the viscosity of the asphalt gradually decreases, the construction and workability of the asphalt mixture gradually increases. When the temperature rises from 5°C to 25°C, the viscosity of the asphalt decreases significantly, indicating that the temperature has an important effect on the viscosity of the asphalt. When the temperature is higher than 25°C, the viscosity of the asphalt gradually becomes stable. Based on the above research, it is recommended that the mixing temperature of cold-mixed asphalt mixture be greater than 25°C.

3. Design of Mixing Proportion Based on Rotary Compaction Method

3.1. Molding Method
Gyratory compaction method is the research result of the US SHRP plan. The factors that affect the compaction effect of the mixture are axial pressure, rotation angle, and rotation speed. The basic principle of the rotary compactor is roughly the same in different countries, but the basic control parameters are different [13-14]. After years of research, the main control technical parameters of the SHRP recommended rotary compactors are shown in Table 7.

| technical parameter | Vertical pressure (kPa) | Rotation angle (°) | Rotation speed (r/min) |
|---------------------|-------------------------|--------------------|------------------------|
| Design value        | 600                     | 1.25               | 30                     |

The American Superpave standard proposes that the reasonable number of gyratory compactions should be determined according to the amount of traffic. The relationship between the design traffic volume and the number of gyratory compactions is shown in Table 8.

| Design traffic / million times | Compaction times / time | Application road |
|-------------------------------|-------------------------|------------------|
| <0.3                          | N_{initial} 6 | 50 75 | Light traffic |
| 0.3–3                         | N_{design} 7 | 75 115 | Medium traffic |
| 3–30                          | N_{maximum} 8 | 100 160 | Medium to heavy traffic |
| ≥30                           | 9 | 125 205 | Heavy traffic |

The gyratory compaction method and the Marshall compaction method were used to form the mixture specimens under different compaction times at normal temperature (25°C). The paper
analyzes the compaction effect of the two molding methods on the mixture. See Table 9 for measured mixture void ratio.

Table 9. Voidage of mixture under different compaction times.

| Compaction times | 50  | 75  | 100 | 150 | 200 |
|------------------|-----|-----|-----|-----|-----|
| Marshall compaction method | 17.8 | 15.2 | 14.8 | 13.2 | 12.5 |
| Gyratory compaction method | 18.4 | 16.1 | 12.3 | 11.5 | 10.7 |

Note: ①Marshall compaction molding procedure: Weigh 1180g of the mixture, at room temperature (25°C), compact double-side for 2/3 of the total number of compactions, and cure for 24 hours in a 25°C oven standing together with the test model. Then take out the test piece and immediately compact double-side for 1/3 of the total number of compaction, and cure at room temperature for 24 hours, and the volume was measured.

②Gyratory compaction molding step: Weigh 4000g of the mixture under room temperature (25°C) and compact for a specified number of times, and keep at room temperature for 24 hours, and the volume is measured.

Figure 5. Change of Voidage of Mixture under Different Compaction Times.

It can be known from the above test that when the number of compaction is less than 75 times, the difference of the voidage of the mixture in the two molding methods is not obvious. With the increase of the number of compaction, the voidage of the gyratory compaction mixture is significantly smaller than that of the Marshall compaction mixture. Among them, the result from 200 times of Marshall's compaction is the same as 100 times of rotation compaction. It shows that the rotary compaction method is easier to make the cold-mixed recycled mixture reach the ideal compaction state.

The Figure shows that as the number of compaction increases, the voidage of the mixture gradually decreases. In the initial stage, the voidage of the mixture decreases significantly. With the increase of the number of compactions, the change of the voidage tends to be smooth. Among them, when the number of gyratory compaction increases from 100 to 200, and the voidage decreases only by 1.6%, which indicates that when the number of compaction is at 100, the mixture has reached a dense state, and increasing the number of times of compaction has no substantial impact on the improvement of the mixture density. In summary, it is recommended that the number of compaction of the cold-mixed recycled mixed material formed by the gyratory compaction method be controlled to 100 times.

3.2. Design Process
Combining with the characteristics of cold-mixed recycled asphalt mixture materials, the paper proposes a cold-mixed recycled mixture mix design method based on the gyratory compaction. The design process is shown in the figure below.
3.3. Determination Method of Optimal Asphalt Content
According to the design grading (see 1.2), the optimal asphalt content of the cold-mixed recycled mixture is determined based on the gyratory compaction method. The cold-mixed asphalt amount is 0.9%, 1.2%, 1.5%, 1.8%, and 2.1% respectively.

3.3.1. Estimated Amount of Asphalt Based on Mixing Uniformity. The desired mixing is reached when the aggregate is evenly wrapped with asphalt. Lacing phenomenon in the mixture indicates the amount of asphalt is not enough. When "Sticky pot" and asphalt flowing phenomenon appears at the bottom of the pot, the amount of asphalt is too much. The test shows that when the amount of asphalt is 1.8%, the asphalt can evenly wrap the aggregate, and the mixture has better mixing uniformity.
3.3.2. Maximum Asphalt Content Based on Initial Strength. Based on the gyratory compaction method, test specimens of different asphalt content mixtures were formed, and the voidage and initial Marshall stability (25°C) were measured. The test results are shown in Table 10.

Table 10. Initial strength index of mixture.

| Asphalt dosage (%) | 0.9 | 1.2 | 1.5 | 1.8 | 2.1 |
|--------------------|-----|-----|-----|-----|-----|
| Voidage (%)        | 15.3| 13.6| 12.2| 12.0| 11.6|
| Marshall stability (kN) | 6.2 | 7.9 | 9.3 | 11.2 | 10.3 |

It can be known from the above tests that as the amount of asphalt increases, the voidage of the mixture gradually decreases, and the inflection point of the voidage curve indicates that the mixture is basically at a dense state, i.e., the minimum amount of asphalt is used. Marshall stability increases first and then decreases, and the peak point of the stability is used as the maximum bitumen usage. In summary, the optimal bitumen amount range is determined to be 1.5% to 1.8%.

3.3.3. Minimum Asphalt Content Based on Sweep Test. The mixture must meet the strength requirements while good abrasion resistance is attained. Based on the gyratory compaction method, a 76±5mm mixture specimen is formed. Put it on a brush tester and wear it for 15 min. The mass loss rate of the mixture specimen is shown in Figure 10.

Figure 8. Asphalt Evenly Wrapped Aggregate State.

Figure 9. Determination of Asphalt Content Based on Initial Strength.
Figure 10. Change of Mass Loss Rate of Mixture Brush Test.

It can be known from the above test that as the amount of asphalt increases, the mass loss rate of the mixture gradually decreases, and the abrasion resistance gradually increases. Relevant specifications require that the mass loss rate of cold-mixed recycled mixtures should not exceed 8%. It can be determined from the Figure 10 that the minimum asphalt content of the mixture should be greater than 1.7%.

Based on the above analysis, the optimum asphalt content of the graded cold-mixed recycled asphalt mixture is 1.8%.

4. Evaluation of the Strength Performance of Cold-mixed Recycled Mixture

4.1. Evaluation Method

The cold-mixed recycled asphalt mixture is mixed under normal temperature conditions. Due to the presence of the diluent in the asphalt, the adhesion in the mixture is poor, and it is not easy to compact, the void between the mixtures is large, and the initial strength is low. With the effect of natural environment and force applied on the load by the traffic, the diluent gradually volatilizes, the mixture is further compacted, the voidage is gradually reduced, and the strength is gradually increased. Therefore, the performance evaluation of cold-mixed recycled asphalt mixture must consider both the initial strength and the final strength.

The evaluation method of initial strength of mixture is: Weigh 4000g of the mixture under normal temperature (25°C) and gyratory compaction for 100 times, measure the volume index at room temperature after curing for 24hrs, and place it in a 25°C water bath to cure for 30 ∼ 45 minutes to measure the Marshall stability of the mixture.

In order to simulate the final strength of the mixture, the molding temperature and compaction times of the mixture are studied in this paper, and the mixture specimen are formed at 20°C, 40°C, 60°C, and 80°C, respectively. Place the evenly mixed mixture on a plate, and spread evenly into a layer of 50mm in thickness, put the plate in an oven at 110°C for 24 hours, cool it down to the molding temperature, and then mold the mixture specimen at the specified temperature, and gyratory compact for 300 times, the change of the voidage of mixture during the molding process is shown in the Figure below.
Figure 11. Variation of Voidage of Mixture.

It can be known from the above test that the voidage of the mixture gradually decreases with the increase of compaction times, and the voidage of the mixture decreases rapidly at the initial stage. After compacting for a certain number of times, the change of the voidage tends to be gentle. It can be seen from the Figure that after 100 times of compaction, the voidage of the mixture tends to be stable. In order to further analyze the change of the voidage of the mixture after 100 times of compaction, the change of the voidage of the mixture after 100 times of gyratory compaction is plotted separately and the linear fitting is performed. The variation rule of the voidage of the mixture is shown in the figure below.

Figure 12. Change Rule of Voidage of Mixture after 100 Times of Gyratory Compaction.

It can be seen from the figure that there is a good linear relationship between the voidage of the mixture and the number of compactions. The slope of the fitting function characterizes the sensitivity of the voidage to the number of compactions. The research shows that the lower the temperature, the more sensitive the voidage of the mixture is to the number of compactions. The main reason is that the
higher the temperature, the easier the mixture is compacted. After compacting for a certain number of times, the mixture reaches the ideal density, and further increase in the number of compactions has no significant effect on the voidage of the mixture. In summary, the research shows that when the number of compaction is 100, the change of the voidage of the mixture tends to be gentle and reaches the specified compactness. The final evaluated strength of the cold-mixed recycled mixture has determined 100 times of gyratory compaction as the standard number of compaction.

According to the above research, 100 times of gyratory compaction was used as the standard number of compactions, and the influence of the molding temperature on the performance of the mixture was further analyzed. The final strength (60°C) of the mixture under different temperature conditions is shown in the figure.

**Figure 13.** Final Strength Index of Mixture at Different Temperatures.

It can be known from the above test that as the molding temperature increases, the voidage of the mixture decreases, and the Marshall stability (60°C) increases. With reference to the design standard of the hot-mixed asphalt mixture, the voidage is controlled to 3%-6%. It can be seen from the figure that the molding temperature of the mixture should be controlled between 55°C and 75°C. At the same time, the Marshall stability curve shows that when the molding temperature is greater than 60°C, the stability of the mixture does not increase significantly, and the final molding temperature is determined to be 60°C.

In summary, the evaluation method to determine the final strength of the mixture is: put the evenly mixed mixture in a plate, spread it evenly into a layer of 50mm in thickness, put the plate in a 110°C oven for 24 hours, then cool it down to 60°C, and perform gyratory compaction for 100 times. Immediately after the compaction is completed, the mold is released at room temperature for 24h, and the volume of the mixture is measured. The mixture is placed in a 60°C water bath for 30 to 45 minutes, and the Marshall stability of the mixture is measured.

4.2. **Evaluation of Strength Performance**

In summary, the initial strength and final strength of the cold-mixed recycled mixture under the optimal asphalt dosage conditions were evaluated. The test results are shown in the following figure.
Figure 14. Evaluation of Strength Performance of Mixture.

It can be seen from the figure that as the Marshall stability of the final strength of the cold-mixed recycled mixture enhances, the voidage is significantly reduced. Because with the volatilization of the diluent, the adhesion of the asphalt increases, and the mixture sticks together into a forced conglomerate, which increases the damage strength of the mixture. At the same time, under the effect of temperature and traffic load, the asphalt mixture is further compacted, the voidage decreases and the density increases significantly.

5. Evaluation of High Temperature Stability of Cold-mixed Recycled Mixtures

5.1. Evaluation Method

High temperature stability refers to the ability of asphalt mixtures to resist permanent deformation under load at high temperature conditions. Insufficient high temperature stability of mixtures is easy to cause rut, slippage and swelling of asphalt pavements [15]. Cold-mixed recycled pavement has poor adhesiveness at early stage of laying and is prone to rut. The rut test is an important method for evaluating the high temperature stability of the mixture. Combined with the characteristics of the cold-mixed recycled mixture, the paper proposes an evaluation method of the initial dynamic stability and the final dynamic stability, and then evaluates the high temperature stability of the cold-mixed recycled mixture.

The evaluation method of the initial dynamic stability of the cold-mixed recycled mixture is: Mix the mixture evenly at room temperature, and form the rut plate specimen of cold-mixed recycled mixture referencing the rut specimen forming method of hot-mixed asphalt mixture, and then carry out rut test after keeping at room temperature for 2 days.

The voidage of the rut plate formed by the above method is 8.5%, which is quite different from the voidage of the final strength of 4.5%. In order to ensure that the mixture achieves the specified density, the paper proposes the final dynamic stability evaluation method for cold-mixed recycled mixtures: Mix the mixture evenly at room temperature, and make the specimen referencing the hot-mixed asphalt mixture rut specimen forming method. Put it in the oven at 110°C for 24 hours, and then take out the specimen and roll it again according to the above method. The rut test is carried out after curing at room temperature for 3 days.

5.2. Evaluation of High Temperature Stability Performance

The initial dynamic stability and final dynamic stability of the cold-mixed recycled mixture were tested respectively, and compared with the hot-mixed asphalt mixture. The test results are shown in the figure below.
Figure 15. Evaluation of High Temperature Stability Performance of Mixture.

It can be known from the above test that the initial dynamic stability of the mixture is low, mainly due to the poor adhesion of the asphalt in the initial stage, while the mixture is still in a loose state, and compaction deformation easily occurs under external force. With the volatilization of the diluent, the final dynamic stability of the mixture is significantly improved, indicating that the high temperature stability of the mixture is greatly improved. The figure shows that the final dynamic stability of the cold-mixed recycled mixture tends to be consistent with that of the hot-mixed asphalt mixture, indicating that with the formation of the strength of the cold-mixed recycled mixture, the mixture has good high temperature stability, but its initial dynamic stability is lower, easy to produce compact rut disease.

6. Water Stability Evaluation of Cold-Mixed Recycled Mixture

6.1. Evaluation Method
Water damage is a common disease on asphalt pavement. Cold-mixed recycled mixture is more prone to water damage due to the lower adhesion of the cementitious material and the larger voidage of the mixture. Based on the hot-mixed asphalt mixture immersion Marshall test and freeze-thaw split test, this paper proposes an evaluation method of modified residual stability and freeze-thaw split strength ratio to evaluate the water stability performance of cold-mixed recycled mixture.

The evaluation method of the residual stability of the mixture is: form the mixture specimen based on the gyratory compaction method (refer to 3.1 above for the forming method of specimen), dividing the cured specimens into two groups, one of which is placed in a 25°C water bath for 48 hours, then the Marshall test was performed; the other group of specimens was placed in a 25°C water bath for 30 minutes, and the Marshall test was performed. The residual stability of the mixture was expressed by the ratio of the stability of the two groups of mixtures.

The evaluation method of the freeze-thaw split strength ratio of the mixture is: form the mixture specimen based on the gyratory compaction method (refer to 3.1 above for the forming method of specimen), dividing the cured specimens into two groups, one of which is stored at room temperature for future use. The other group of specimens were water-saturated according to the saturated test method. Then put the test specimens into plastic bags, add about 10ml of water, and put them in a refrigerator at a temperature of -18±2°C, and hold them for 16±1 hours. After taking out the specimens, they were placed in a 40±0.5°C constant temperature water tank for 24 hours. Finally, two groups of specimens were placed in a 25±0.5°C constant temperature water tank for not less than 2 hours. The split strength of the two groups of specimens was measured.

6.2. Evaluation of Water Stability Performance
Based on the above methods, the water stability of the initial strength and final strength of the mixture was tested and analyzed. The test results are shown in the following Figure.
Figure 16. Evaluation of Water Stability of Mixture.

According to the above tests, it is known that the water stability of the mixture is poor at the initial stage and barely meets the specification. Because the asphalt and the aggregate have poor adhesion at the initial stage, the voidage between the mixture is large, and water enters the mixture and it is easy to produce hydrodynamic pressure under the action of thermal stress, which will damage the space structure of the mixture and cause the aggregate to spall and loose. The Figure shows that as the strength develops, the final water stability performance of the cold-mixed recycled mixture will be significantly improved. In summary, the research shows that the cold-mixed recycled mixture has poor water stability at the initial stage, and is prone to diseases such as flying and spalling. With the formation of strength, the water stability of the mixture gradually increases.

7. Conclusions
(1) The fine aggregate and mineral powder adhere to asphalt and exist in the form of agglomeration in the Reclaim Asphalt Pavement (RAP), which will cause the gradation of the milling plan material to decay after extraction. Adding the cold-mixed asphalt can partially restore the aged asphalt to its original performance. It is recommended that the mixing temperature of the mixture be greater than 25°C according to the viscosity characteristics of the cold-mixed asphalt.

(2) Comparing the compaction effect of Marshall compaction method and gyratory compaction method on the cold-mixed recycled mixture, it is shown that the compaction of the cold-mixed recycled mixture is much easier to achieve if the gyratory compaction method is used. A method for determining the optimum asphalt content of cold-mixed recycled mixture through initial strength and sweep test based on the gyratory compaction method is proposed.

(3) Based on the characteristics of cold-mixed recycled mixtures, a method for evaluating the final strength of the mixture is proposed: put the evenly mixed mixture in a plate, spread it evenly into a layer of 50mm in thickness, put the plate in a 110°C oven for 24 hours, then cool it down to 60°C, and perform gyratory compaction for 100 times. Immediately after the compaction is completed, the mold is released at room temperature for 24hrs, and the volume of the mixture is measured. Studies have shown that comparing with the initial strength, the voidage of the mixture is significantly reduced, and the Marshall stability is significantly enhanced.

(4) An evaluation method for the final high temperature stability and water stability of the cold-mixed recycled mixture is proposed. Studies have shown that the initial stage of the mixture is prone to water damage and compaction rut. As the strength gradually forms, the high temperature stability and water stability are significantly improved, and the performance of the mixture is not different from that of the hot-mixed asphalt mixture.
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