Application of In-situ Thermal Regeneration Technology in Southern Ring Section of Guangzhou Ring Expressway

Chenchu Peng, Fang Yang, Liu Feng
Guangdong Hualu Communications Technology Co. LTD, Guangzhou, 510420, China

Abstract. Based on the South Ring Section of Guangzhou Circum-City Expressway, the characteristics of in-situ thermal regeneration and pavement regeneration technology are analyzed. The pavement performance of the mixture is evaluated by means of immersion residual stability, rutting and freeze-thaw splitting test. The application effect of in-situ thermal regeneration pavement is evaluated by means of seepage test and structural depth test. The results show that the water stability and high temperature stability of recycled asphalt mixture after adding recycling agent are in line with the specifications; the segregation of recycled pavement is large, the seepage is serious, and the seepage and structural depth of overlay recycled pavement meet the requirements; this paper summarizes the application experience and problems in the application process, and provides a reference for similar projects. Basis and improvement direction.

Key words: In-situ thermal regeneration, Asphalt mixture, Pavement performance, SMA-10 overlay.

1. Introduction
Asphalt pavement on-site geothermal regeneration technology refers to the construction technology of using on-site geothermal regeneration unit, heating the old asphalt pavement, adding recycled agent, new asphalt mixture and other materials after harrowing, and directly paving the original pavement after mixing at the construction site. This technology has little interference on traffic, fast construction speed, and can make 100% use of waste asphalt mixture, so it has been gradually promoted and applied in the country in recent years [1-5]. However, the applicability of this technology to the high temperature and rainy climate in Guangdong, especially the applicability of different geothermal regeneration technologies, is still very lacking. In December 2018, the south ring section of Guangzhou Ring Expressway implemented the geothermal regeneration treatment on the Leiliu interchange ramp and some main lines, aiming to study the geothermal regeneration technology and its applicability in hot and humid areas.

2. Original pavement condition and pavement structure scheme

2.1. original pavement condition
Take samples from the wheel track belt of the D ramp of Leliu interchange in the geothermal regeneration section, heat the old mixture of the original road in the room, extract the old asphalt by the
extraction method, and add different amount of regenerant into the old asphalt to test its penetration, softening point and 135 ℃ kinematic viscosity index. The test results are shown in Table 1, in which the amount of regenerant is the percentage of the quality of the old asphalt.

Table 1. Test results of old asphalt and adding different amount of regenerant

| project                        | Penetration (0.1mm) | Softening point (℃) | 135 ℃ kinematic viscosity (Pa.s) |
|--------------------------------|---------------------|----------------------|----------------------------------|
| Old asphalt                    | 26                  | 58.0                 | 0.89                             |
| Original asphalt + 3% regenerant| 38                  | 54.0                 | 0.61                             |
| Original asphalt + 5% regenerant| 48                  | 51.0                 | 0.54                             |

The penetration of the old asphalt sample is 26, which meets the requirements of the specification for recycling asphalt with geothermal energy; the old mixture of the original pavement is heated indoors, and all mineral materials are extracted by extraction method, and the screening test results are shown in Table 2.

Table 2. Gradation of old asphalt mixture after extraction

| Mesh size (mm) | Pass rate of aggregate grading of AC-13 (%) |
|----------------|---------------------------------------------|
| Detection result | Upper limit of gradation | Lower limit of gradation |
| 16              | 100.0                                      | 100                       | 100                       |
| 13.2            | 93.5                                       | 100                       | 90                        |
| 9.5             | 67.8                                       | 85                        | 68                        |
| 4.75            | 34.8                                       | 68                        | 38                        |
| 2.36            | 25.9                                       | 50                        | 24                        |
| 1.18            | 14.7                                       | 38                        | 15                        |
| 0.6             | 10.2                                       | 28                        | 10                        |
| 0.3             | 5.4                                        | 20                        | 7                         |
| 0.15            | 2.9                                        | 15                        | 5                         |
| 0.075           | 1.3                                        | 8                         | 4                         |

It can be seen from the test results that the gradation of the original pavement mixture exceeds the lower limit of gradation specified in the specification.

2.2. pavement structure scheme

According to the situation of the original road surface, in order to compare the effect of different ways of geothermal regeneration, two ways of geothermal regeneration are designed. One is to repaint the original road surface by heating the original road surface with the depth of 4cm with the local geothermal regeneration unit and adding the regeneration agent. The other is to repaint the original road surface with the depth of 4cm with the local geothermal regeneration unit by milling and then spreading the milk Turn the asphalt tack coat and pave 2cm SMA-10 overlay on the upper part. Hot air heating is adopted for geothermal regeneration heating. In order to reduce aggregate crushing, the maximum depth of heating rake should not exceed 4cm. The pavement structure scheme is shown in Fig. 1, Fig. 2 and Fig. 3.

![Fig. 1 original pavement structure](image1)
![Fig. 2 remixing and regeneration](image2)
![Fig. 3 overlay regeneration](image3)
3. Mix Design

3.1. Recycling asphalt mixture with geothermal energy
Heat the old mixture of the original road in the room, use Marshall compaction method [6-8], design the hot recycled mixture with different amount of regenerant and different molding temperature, and test its theoretical maximum relative density, gross volume relative density, void ratio and other indicators, the results are shown in Table 3.

| Regenerant dosage(%) | Molding temperature (%) | Theoretical maximum relative density | Gross volume relative density | Void ratio (%) detection result | technical requirement |
|----------------------|-------------------------|-------------------------------------|------------------------------|---------------------------------|-----------------------|
| 0                    | 130                     | 2.530                               | 2.397                        | 5.23                            | 4-6                   |
| 0                    | 140                     | 2.530                               | 2.412                        | 4.66                            |                       |
| 3                    | 120                     | 2.546                               | 2.501                        | 1.77                            |                       |
| 1.5                  | 130                     | 2.546                               | 2.499                        | 1.83                            |                       |
| 3                    | 140                     | 2.526                               | 2.504                        | 0.85                            |                       |
| 3                    | 150                     | 2.526                               | 2.508                        | 0.70                            |                       |

It can be seen from the results that the void ratio of asphalt mixture can meet the requirements of the specification when there is no regenerant and the molding temperature is 140 °C.

3.2. SMA-10 asphalt mixture
Marshall design method was used to design the mixture proportion. See Table 4 below for the comprehensive grading of mineral aggregate of mixture.

| project       | Sieve passing rate (%) |
|---------------|-------------------------|
|               | 13.2  | 9.5  | 4.75 | 2.36 | 1.18 | 0.6  | 0.3  | 0.15 | 0.075 |
| Upper limit   | 100   | 100  | 60   | 32   | 26   | 22   | 18   | 16   | 13    |
| lower limit   | 100   | 90   | 28   | 20   | 14   | 12   | 10   | 9    | 8     |
| Design gradation | 100.0 | 99.2 | 47.5 | 24.7 | 19.1 | 17.0 | 14.1 | 12.2 | 11.3  |

The mixing process in the mixture room is as follows: the heating temperature of asphalt is controlled at 160-165 °C; the heating temperature of mineral aggregate is 190-200 °C; the mixing temperature of mixture is 175 °C, the compaction temperature is 165-170 °C; the mixing amount of lignin fiber is 0.4% of the asphalt mixture. Adjust the oil stone ratio, and conduct the test with the oil stone ratio of 6.0%, 6.3%, 6.6% and formed Marshall test pieces. The results are shown in Table 5:

| Specimen number | Oil stone ratio (%) | Relative density of test piece | Void ratio (%) | Mineral aggregate Clearance rate (%) | asphalt saturation (%) | Stability (KN) | Stream value (mm) |
|-----------------|---------------------|-------------------------------|----------------|-------------------------------------|-----------------------|----------------|-------------------|
|                 |                     | theoretical | Measured         |                        |                        |                |                   |
| 1               | 6.0                 | 2.459         | 2.347             | 4.5                   | 17.1                  | 73.4           | 10.17             | 2.97              |
| 2               | 6.3                 | 2.449         | 2.356             | 3.8                   | 17.0                  | 77.7           | 10.06             | 3.34              |
| 3               | 6.6                 | 2.440         | 2.375             | 3.1                   | 16.9                  | 81.7           | 9.68              | 3.81              |
| technical requirement | ~     | ~            | ~                 | ~                     | ~                     | ~              | ~                 | ~                 |
It can be seen from the above table that Marshall test results analysis shows that the Marshall indexes measured by 6.3% asphalt aggregate ratio meet JTG F40-2004 specifications and design requirements.

4. Way performance analysis

4.1. Recycled asphalt mixture
At the construction site, the recycled asphalt mixture after harrowing is taken, and Marshall and rutting board test pieces are formed indoors for the recycled asphalt mixture sampled in situ, and the void ratio, residual stability, freeze-thaw splitting strength ratio and dynamic stability are tested, and the forming temperature of the test piece is 140 °C. The results are shown in Table 6.

| number | Void ratio (%) | Residual stability (%) | Freeze thaw splitting strength ratio (%) | Dynamic stability (times / mm) |
|--------|----------------|------------------------|----------------------------------------|-----------------------------|
| 1      | 6.31           | 100.5                  | ---                                    | 4468                        |
| 2      | 5.71           | 98.9                   | 95.2                                   | 4565                        |
| technical requirement | ----- | 85                     | 80                                     | ≥2800                       |

The test results show that the water stability and high temperature performance of recycled asphalt mixture meet the specification requirements.

4.2. SMA-10 asphalt mixture
Sherenberg asphalt leakage test [9-10] was used to test the leakage loss, rut test was used to evaluate the high-temperature stability of the hot recycled mixture, Kentucky immersion dispersion test, immersion Marshall test and freeze-thaw split test were used to evaluate the water stability of the hot recycled mixture [11-14]. The indoor formed rutting board is tested for water penetration and structural depth to test the skid resistance and watertight performance of the pavement. See Table 7 for the test results.

| Test contents | Ratio of oil to stone (%) | Dynamic stability (times / mm) | Leakage loss (%) | Residual stability (%) | Splitting tensile strength ratio (%) | Seepage coefficient (ml / min) | Structural depth (mm) |
|---------------|---------------------------|-------------------------------|-----------------|------------------------|--------------------------------------|--------------------------|----------------------|
| test result   | 6.3                       | 10353                         | 0.07            | 90.4                   | 91.6                                 | Impervious water         | 1.05                 |
| technical requirement | ----- | ≥3000                         | ≤0.1%           | ≥80                    | ≥80                                  | ≤80                      | ------               |

The best asphalt to aggregate ratio is 6.3%. All indexes of Marshall test, sherenberg asphalt leakage test and Kentucky dispersion test meet the technical requirements of JTG F40-2004 for SMA-10 modified asphalt mixture. The results of water stability test, high temperature stability rutting test and water penetration test of asphalt mixture test pieces all meet the technical requirements of JTG F40-2004 for SMA-10 modified asphalt mixture.

5. Application effect evaluation

5.1. Remixing regeneration layer
Take samples of the constructed geothermal regeneration road surface at the C and D ramps of Leliu interchange. No regenerant is added at the sampling point. The oil stone ratio is extracted and screened indoors and the penetration, softening point and 135 °C kinematic viscosity of the extracted asphalt are
tested. The results are shown in Table 8. The water penetration test is carried out for the geothermal regeneration road section of a, C and D ramps of Leliu interchange. The results are shown in Table 9.

### Table 8. Sampling test results of hot recycled mixture

| Ramp number | Oil stone ratio (%) | Softening point (℃) | Penetration (0.1mm) | 135 °C kinematic viscosity (Pa.s) |
|-------------|---------------------|----------------------|---------------------|----------------------------------|
| 1           | 4.68                | 55.0                 | 31                  | 0.72                             |
| 2           | 4.46                | 57.4                 | 22                  | 0.64                             |

### Table 9. Water seepage detection of geothermal regeneration section

| Pile number position | Test results | Station position | Test results |
|----------------------|--------------|------------------|--------------|
| AK0+550 Carriageway   | 143.3        | CK1+000 Carriageway | 250.0        |
| AK0+600 Carriageway   | 212.8        | CK1+000 Carriageway | 198.7        |
| CK0+350 Carriageway   | 252.1        | CK0+900 Carriageway | 245.9        |
| CK0+500 Carriageway   | 240.0        | DK0+060 Shoulder   | 133.3        |
| CK0+600 Carriageway   | 241.9        | DK0+112 Shoulder   | 133.3        |
| CK0+700 Carriageway   | 198.7        | DK0+065 Carriageway | 32.7         |
| CK0+700 Carriageway   | 156.7        | DK0+470 Carriageway | 181.8        |
| CK0+800 Carriageway   | 33.3         | DK0+548 Carriageway | 255.3        |
| CK0+800 Carriageway   | 143.3        |                   |              |
| technical requirement| ≤300         |                   |              |

From the test results, it can be seen that the segregation degree of asphalt pavement on site is relatively large, and the penetration degree of aging asphalt is 22 and 31 respectively, which is quite different; the water permeability coefficient of a ramp, C ramp and D ramp meets the specification requirements, and the qualified rate is 100%.

5.2. **Add regeneration layer**

Take the core of the additional layer, test the relative density, thickness and water permeability coefficient of the gross volume of the core sample indoors, and calculate the compactness and porosity. The results are shown in table 10.

### Table 10. Test results of SMA-10 overlay core sample

| Pile number | Vehicle Lane | Gross volume relative density | Theoretical maximum relative density | Voidage (%) | Core sample thickness (mm) | Degree of compaction (%) | Structural depth TD (mm) |
|-------------|--------------|-------------------------------|--------------------------------------|-------------|----------------------------|--------------------------|--------------------------|
| AK103+5000 Overtaking Lane | 2.321 | 2.463 | 5.7 | 20 | 94.3 | 0.85 |
| AK103+6000 Overtaking Lane | 2.352 | 2.463 | 4.5 | 21 | 18.4 | 95.5 | 0.94 |
| AK103+8000 Slow lane | 2.335 | 2.463 | 5.2 | 23 | 94.8 | 1.03 |
| AK104+1000 Overtaking Lane | 2.319 | 2.463 | 5.8 | 19 | 94.2 | 1.06 |

It can be seen from the test results that the compactness, thickness and structural depth of the core sample can meet the requirements, and the qualified rate is 100%; no water seepage is found in the test of the added recycled layer.
6. Precautions and Solutions

6.1. Temperature
For the geothermal regeneration unit, the hot air heating method is adopted, and three groups of units are used for heating. After the first group of units are heated, the surface temperature of asphalt pavement is 110 °C, after the second group is heated, the surface temperature of asphalt pavement is 160 °C, after the third group is heated, the surface temperature of asphalt is high, and asphalt bubbles appear on the pavement. After the three groups are heated, the pavement begins to be milled, and the aggregate temperature after milling is 130 °C, and milling is found on site. The old planer aggregate is seriously broken, and there are many broken surfaces. The main reason for this is that the heat transfer time of asphalt pavement is too short, the surface temperature is too high, and the bottom temperature is low, which causes the bottom aggregate to be broken during milling. Therefore, a heat transfer section should be added in the construction process to control the surface temperature at about 180 °C and the bottom temperature at 130 °C.

6.2. mixture segregation
During the construction process, there are obvious thick and thin segregation zones in some road sections, and the detailed segregation zones are in the middle of the road surface, and the coarse segregation zones are mostly concentrated in the side of the road surface. The main reason is that the unit is not equipped with a compound mixing cylinder, only equipped with a mixing shaft, which causes the coarse material to be pushed to the side, and the fine aggregate to be concentrated in the middle; therefore, the road surface appears the intuitive phenomenon of oil spilling in the middle and dry edge. In order to solve this problem, it should be considered from the aspect of unit configuration. A compound mixing tank should be equipped to collect the aggregate and mix it in the compound mixing tank, and then pave it with a paver, which can solve the problem of aggregate segregation to a better extent.

6.3. sampling representativeness
After reheating and re paving the original pavement with geothermal regeneration technology, it can effectively solve the problems such as poor flatness of the original pavement, rut disease, etc., but the construction quality control difference in the process of expressway construction makes the original pavement gradation, asphalt content, etc. have great variability. In the process of geothermal regeneration construction, whether it is re mixing regeneration or re paving regeneration, only adding a fixed amount of re mixing raw material, without considering the gradation difference in the construction process of the original pavement, cannot adjust the construction quality of the original pavement. For the construction of geothermal regeneration, generally before the construction, a certain sample is taken at the site, and a mix proportion is determined indoors. During the treatment process, the mix proportion is used for construction for a long time, which causes part of the road surface on the construction site to be oily while some of the road surface is very dry. Therefore, in the construction process of geothermal regeneration, we should pay attention to the sampling work, divide the sections according to the severity of the disease, carry out the mix proportion design indoor after each section of sampling, and then adjust the mix proportion continuously during the construction process according to the mix proportion design.

7. Conclusion
(1) The water stability and high temperature stability of the recycled asphalt mixture meet the requirements of the code after adding the regenerant to the geothermal recycled mixture.
(2) It is difficult to control the uniformity of pavement in the process of compound mixing and regeneration. During the construction, the sampling frequency should be increased, the sections should be divided according to the diseases, and the mix proportion should be adjusted.
(3) In the geothermal regeneration technology, the water seepage and the structural depth of the additional pavement are better, which has better road performance.
(4) In order to solve the problem that the surface temperature is too high and the bottom temperature is too low in the process of road heating, a heat transfer distance should be increased for the geothermal regeneration unit.

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