Research on the Maximum Amount of Reclaimed Asphalt Pavement Based on Balanced Design of Performance and Economy

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Abstract. By controlling the variability of Reclaimed Asphalt Pavement (RAP) and achieving the goal of high content, it is proposed that the milling speed of RAP should be controlled at 5 ~ 7m / min, the moisture content should not be greater than 2%, and there should be at least two levels of pretreatment technology. The maximum RAP content of AC-25 hot recycling is 50% according to the grading calculation curve under the condition that the current standard grading range and powder binder ratio are not greater than 1.3. At the same time, according to the grading calculation of the project, the empirical formula of coarse and fine aggregate mix to realize the balanced design of utilization and economy is put forward.

1. Introduction
Up to now, the total length of highways in China is 4.77 million kilometers, including 136,000 kilometers of freeway. The recycling of used materials reaches 70 to 90 million tons each year. In the past, Reclaimed Asphalt Pavement (RAP) material were completely abandoned. Due to the introduction of environmental protection policies and excessive mining, the form of obtaining raw materials for road construction projects in Shandong province in the past two years is extremely severe, and there are some phenomena such as stone shortage, quality decline and high purchase cost of raw materials. From the perspective of green development concept and economic benefits, asphalt recycling has become a hot topic in road research, and the improvement of RAP material utilization is particularly critical.

2. RAP material grading control requirements

2.1. The effect of milling rate on RAP gradation
In this paper, two milling rates (3m/min and 6m/min) are studied for single structure layer milling. The RAP material screen was divided into two sections: 0-9.5mm and 9.5-19mm, and the material was taken for extraction and screening test respectively to analyze the gradation change, as shown in the figure1.
Fig 1. RAP grading coefficient of variation

1. For the same material, the coefficient of variation decreases with the increase of mesh size.
2. For the same gear material, the material obtained by slow milling, the variability is smaller. However, there is no significant difference between the variation of materials obtained by slow milling and fast milling. In view of the practical engineering and economic principles, it is recommended to adopt fast milling with a speed of 5~7m/min.

2.2. RAP material classification pretreatment requirements
Sometimes the gradation of recycled asphalt mixtures from different sources on different roads can vary widely, even if the aggregate gradation of the asphalt mixtures milling on the same road surface is different. The variation of gradation of recycled asphalt will affect the road performance of recycled asphalt mixture. In order to reduce RAP variation, RAP should be broken and processed.

In this paper, by comparing and analyzing the variability of crushing sieve (the primary crushing is jaw crushing, the secondary crushing is roll crushing) and the uncrushed RAP material, a reasonable sorting method is put forward.

Fig 2. gradation variation of RAP screening and untreated

According to the figure, the impact of variability of used materials can be effectively reduced by crushing and screening, and RAP crushing and screening treatment can effectively reduce the dispersion of grading and reduce variability. The gradation variation was significantly greater than that of the gradation variation after crushing, and the gradation variation was smaller in the sieve holes of 2.36mm.
and 4.75mm. The coefficient of variation of gradation above 9.5mm and below 1.18mm is large, indicating that the gradation of ore material varies greatly at both ends.

After crushing and screening, gradation variability was significantly reduced, especially with gradation variation greater than 9.5mm and less than 1.18mm. Compared with that without screening, RAP gradation variability of each grade was better controlled after crushing and screening. The crushing and screening can effectively control the RAP uniformity, reduce the gradation variability, and ensure the road performance of the recycled asphalt mixture. Therefore, it is necessary to treat the waste asphalt mixture by crushing and screening.

The recycled waste asphalt mixture (RAP) material after treatment is divided into no less than two grades of materials. The recycled large asphalt mixture blocks need to be broken and sieved according to the recycling requirements to reduce the variability of RAP recycled materials.

### 3. Study on the influence of RAP material grading on high content

The milling materials of Beijing Shanghai bid section 1 are used. The milling materials are set in two grades of 0-10 mm and 10-20 mm. The extraction and screening results of milling materials of each grade are shown in the table.

| Sample number | Weight of mixture, g | Aggregate weight, g | Weight of asphalt, g | Asphalt dosage, % | Corrected value, % | Average value after correction, % |
|---------------|---------------------|---------------------|---------------------|-------------------|-------------------|-------------------------------|
| 1#            | 1512.5              | 1480.4              | 32.1                | 2.1               | 0                 | 2.1                           |
| 2#            | 1546.8              | 1514.2              | 32.6                | 2.1               |                   |                               |

| Mesh size, mm | Separate sieve residue, g | Separate sieve residue, g | Passing rate, % | Passing rate, % | Average passing rate, % | Average passing rate, % |
|---------------|---------------------------|---------------------------|----------------|----------------|-------------------------|-------------------------|
| 26.5          | 0                         | 0                         | 100.00         | 100.00         | 100.00                  | 100.00                  |
| 19            | 37.0                      | 27.6                      | 97.50          | 98.14          | 97.82                   | 97.82                   |
| 16            | 230.9                     | 254.3                     | 81.90          | 81.39          | 81.64                   | 81.64                   |
| 13.2          | 273.9                     | 292.3                     | 63.40          | 62.08          | 62.74                   | 62.74                   |
| 9.5           | 450.0                     | 460.8                     | 33.00          | 31.65          | 32.33                   | 32.33                   |
| 4.75          | 205.8                     | 205.6                     | 19.10          | 18.07          | 18.59                   | 18.59                   |
| 2.36          | 72.5                      | 47.0                      | 14.20          | 14.97          | 14.59                   | 14.59                   |
| 1.18          | 22.2                      | 43.5                      | 12.70          | 12.10          | 12.40                   | 12.40                   |
| 0.6           | 42.9                      | 29.7                      | 9.80           | 10.14          | 9.97                    | 9.97                    |
| 0.3           | 41.5                      | 49.6                      | 7.00           | 6.86           | 6.93                    | 6.93                    |
| 0.15          | 26.6                      | 29.9                      | 5.20           | 4.89           | 5.04                    | 5.04                    |
| 0.075         | 19.2                      | 15.4                      | 3.90           | 3.87           | 3.88                    | 3.88                    |
| Bottom sieve  | 57.7                      | 58.6                      |                |                |                         |                         |
| Total         | 1480.4                    | 1514.2                    |                |                |                         |                         |

Table 1. Extraction and screening results of 9.5-19mm milling material
Table 2. 0-10 mm milling material extraction and screening results

| Sample number | Weight of mixture, g | Aggregate weight, g | Weight of asphalt, g | Asphalt dosage, % | Corrected value, % | Average value after correction, % |
|---------------|----------------------|---------------------|----------------------|------------------|-------------------|----------------------------------|
| 1#            | 1460.9               | 1390.5              | 70.4                 | 4.8              |                   | 4.8                              |
| 2#            | 1469.9               | 1400.1              | 69.8                 | 4.7              |                   | 4.7                              |

| Mesh size, mm | Separation sieve residue, g | Separation sieve residue, g | Passing rate, % | Passing rate, % | Average passing rate, % |
|---------------|-----------------------------|-----------------------------|----------------|----------------|-------------------------|
| 13.2          | 0                           | 0                           | 100.00         | 100.00         | 100.00                  |
| 9.5           | 18.1                        | 25.7                        | 98.70          | 98.17          | 98.43                   |
| 4.75          | 353.2                       | 363.6                       | 73.30          | 72.20          | 72.75                   |
| 2.36          | 319.8                       | 316.7                       | 50.30          | 49.58          | 49.94                   |
| 1.18          | 154.3                       | 152.7                       | 39.20          | 38.67          | 38.94                   |
| 0.6           | 178.0                       | 152.4                       | 26.40          | 27.79          | 27.09                   |
| 0.3           | 115.4                       | 159.1                       | 18.10          | 16.43          | 17.26                   |
| 0.15          | 64.0                        | 55.1                        | 13.50          | 12.49          | 12.99                   |
| 0.075         | 40.3                        | 33.8                        | 10.60          | 10.08          | 10.34                   |
| Bottom sieve  | 147.4                      | 141.1                      | 0.00           | 0.00           | 0.00                    |
| Total         | 1390.5                     | 1400.1                     |                 |                 |                         |

After crushing and screening, 10-20 mm milling material: 0-10 mm milling material ≈ 1:3. According to the characteristics of the project, considering the efficient utilization of the milling material, keep 10-20 mm milling material: 0-10 mm milling material = 1:3 in the grading debugging process. According to the screening results of each raw material, AC-25 gradation for Beijing Shanghai project are synthesized. The grading calculation table is shown in the following table:

Table 3. AC-25 proportion of raw materials

| Sieve size            | Grading 1 | Grading 2 | Grading 3 | Grading 4 | Grading 5 | Grading 6 | Grading 7 |
|-----------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| 20-30mm gravel        | 12        | 12        | 12        | 12        | 12        | 12        | 12        |
| 10-20mm gravel        | 29        | 27        | 25        | 24        | 20        | 18        | 0         |
| 5-10mm gravel         | 19        | 14        | 11        | 8         | 8         | 0         | 0         |
| 10-20mm RAP material  | 5         | 7.5       | 10        | 12.5      | 15        | 17.5      | 20        |
| 0-10mm RAP material   | 15        | 22.5      | 30        | 37.5      | 45        | 52.5      | 60        |
| 0-5mm fine aggregate  | 18        | 16        | 11        | 6         | 0         | 0         | 0         |
| mineral powder        | 2         | 1         | 1         | 0         | 0         | 0         | 0         |
As can be seen from the above:

(1) The proportion of coarse and fine milling materials is adjusted according to 1/3 control. The RAP content of AC-25 asphalt mixture can reach 70%, under the condition of meeting the standard grading range. Compared with coarse-grained asphalt mixture, medium grained asphalt mixture has higher utilization rate of milling material.

(2) Through literature research, according to the research results of conventional hot mix asphalt mixture, that is, with the increase of power ratio, the high-temperature performance of asphalt mortar is improved. When it increases to a certain extent, the improvement range of high-temperature performance is obviously reduced. From the analysis of high-temperature performance index, the filler-asphalt ratio should not exceed 1.4; with the increase of filler-asphalt ratio, the low-temperature performance of asphalt mortar becomes worse. Considering the low temperature performance, the filler-asphalt ratio should not exceed 1.2; in the design of asphalt mixture, when determining the asphalt dosage and the final gradation curve of the mixture, the filler-asphalt ratio (0.075mm pass rate of grade blending / asphalt dosage) should be strictly controlled, and the passing amount of 0.075mm should be determined by water screening method.

The filler-asphalt ratio of the project is controlled to be less than 1.3[1,2]. According to the grading calculation curve, the maximum RAP content of AC-25 asphalt mixture is 50%.

(3) According to the grading commissioning of the project, since the recycled materials from milling are all continuous grading. No matter whether the milling material is divided into two or three grades, the milling material can still synthesize a continuous grading curve through reasonable step matching, and the gradation can be optimized by adding a certain proportion of new aggregate.

It is found that the RAP content of coarse-grained asphalt mixture with two-stage preparation is close to 80% without considering the filler-asphalt ratio, and the newly added aggregate is 20-30mm. If RAP is prepared in three grades (0-5mm, 5-10mm, 10-20mm), although it reduces the variation of milling materials of each grade, it has little effect on improving RAP utilization rate, and the screening efficiency of 0-5mm RAP is greatly affected by moisture content. Comprehensive consideration, it is suggested to adopt two grades of material preparation for this project.
(4) The preliminary design of plant mixed hot recycled asphalt mixture should ensure the reasonable mix of coarse and fine aggregate. Since the finer milling material is much more than the coarse one in crushing and screening process, under the condition of uncertain coarse to fine aggregate ratio after RAP aggregate screening, the principle of RAPfine > RAPcoarse is followed in the grading debugging process, and the final grading curve is determined according to the scope of current specifications. At the same time, the filler-asphalt ratio of the grading curve is tested to ensure that the filler-asphalt ratio under the conventional asphalt dosage is less than 1.3, so as to realize the balanced design of utilization and economy. The specific calculation formula is as follows:

\[
\begin{align*}
\text{RAP}_{\text{fine}} &= a, \quad \text{RAP}_{\text{coarse}} = 0 \quad (a > 20\%); \\
\text{RAP}_{\text{fine}} > \text{RAP}_{\text{coarse}}; \quad \text{RAP}_{\text{fine}} + \text{RAP}_{\text{coarse}} &= a \quad (a > 20\% \text{ and the milling material on the project is surplus}) \\
\text{RAP}_{\text{fine}} / \text{RAP}_{\text{coarse}} &= b \quad \text{(measurement results)}; \quad \text{RAP}_{\text{fine}} + \text{RAP}_{\text{coarse}} = a \quad \text{(all the recycled materials required for milling in the project shall be applied)}
\end{align*}
\]

In the formula, \(a\) is the total amount of hot recycled mixture milling material. At the same time, after the grading calculation is completed, it is necessary to check that the filler-asphalt ratio under the conventional asphalt dosage is less than 1.3.

4. Study on the influence of preheating temperature on high content of RAP

In the process of asphalt pavement construction, if the mixing temperature and compaction temperature of the mixture cannot meet the requirements, the problems such as segregation and large porosity will occur in the construction process, and the pavement will cause early damage such as rutting and water damage. Therefore, the control of mixing pressure temperature is always the core link of mixture mixing process. Due to the complexity of material composition of plant mixed hot recycled mixture, it is necessary to carry out in-depth study on the temperature of mixing material, which is affected by many factors.

4.1. Preheating temperature of RAP material

There is no uniform standard for the preheating temperature of RAP, which is mostly determined by the heating capacity of the actual equipment. The consensus is that the preheating temperature of RAP should be determined in a reasonable range. When the heating temperature of RAP is too low, in order to meet the discharge temperature of mixture, it is necessary to increase the heating temperature of new materials excessively, resulting in the decline of the quality of new aggregates. The consensus is that the preheating temperature of RAP should be determined in a reasonable range. When the heating temperature of RAP is too low, in order to meet the discharge temperature of mixture, it is necessary to increase the heating temperature of new materials excessively, resulting in the decline of the quality of new aggregates. However, if the heating temperature is too high, on one hand, asphalt in RAP materials will be dissolved, which will cause RAP materials to stick into agglomerates and block the equipment, on the other hand, it will cause the further aging of aged asphalt in RAP, which will affect the quality of recycled mixture.

Some scholars in China believe that the reasonable heating temperature of RAP is between 80-100 °C, and the standard of recycled asphalt concrete in Taipei also stipulates that RAP heating temperature is not more than 110 °C. Ren Shuzhe of Chang'an University thinks that the temperature range is low. Through the indoor study of the influence of different heating temperature of old materials on the asphalt further aging performance and the road performance of recycled mixture, the reasonable heating temperature of RAP material is 110-130 °C. Through design test, the NCHRP project in the United States studies the change of performance index of high and low temperature of RAP material by extraction and recovery asphalt under different preheating temperature and preheating time. It is concluded that in order to avoid the secondary aging RAP material of asphalt binder, the preheating temperature should not exceed 130 °C and the reasonable preheating time is 1.5h-3h. In the actual
production process, the RAP heating temperature should be adjusted according to the RAP content and the aging degree of RAP materials.

4.2. Temperature of recycled mixture

The mixing discharge temperature of recycled mixture is not only affected by the heating temperature of new aggregate, but also related to the water content of RAP, RAP content and preheating temperature of RAP material. In this project, the reasonable heating temperature of RAP and new aggregate under different RAP content was further determined through laboratory trial mixing.

In the trial mixing test, the preheating temperature of RAP is 70 ℃, 90 ℃, 110 ℃ and 120 ℃; the preheating temperature of new material is 185 ℃, 200 ℃ and 215 ℃; in order to ensure the full preheating of the aggregate and eliminate the influence of water content of the aggregate as far as possible, the holding time of RAP material is 2h, and the holding time of new material is 4h; the dosage of RAP is 30%, 40%, 50% and 60%, the mixing pot temperature is 165 ℃ and the mixing time is 90 s. After the recycled mixture is mixed, the thermometer is used to test the temperature at three different positions of the recycled mixture, and the average value is taken as the outlet temperature of the recycled mixture. The test results are shown in the table.

| Preheating temperature of RAP material (℃) | Preheating temperature of new aggregate (℃) | Discharge temperature of mixture with different RAP content (℃) |
|------------------------------------------|---------------------------------------------|---------------------------------------------------------------|
|                                          |                                             | 30% | 40% | 50% | 60% |
| 70                                       | 185                                         | 120 | 115 | 110 | 105 |
| 70                                       | 200                                         | 133 | 125 | 120 | 115 |
| 70                                       | 215                                         | 140 | 135 | 125 | 120 |
| 90                                       | 185                                         | 140 | 135 | 125 | 120 |
| 90                                       | 200                                         | 145 | 138 | 130 | 120 |
| 90                                       | 215                                         | 149 | 142 | 135 | 130 |
| 110                                      | 185                                         | 150 | 145 | 135 | 130 |
| 110                                      | 200                                         | 155 | 153 | 150 | 140 |
| 110                                      | 215                                         | 167 | 165 | 160 | 150 |
| 120                                      | 185                                         | 152 | 147 | 143 | 140 |
| 120                                      | 200                                         | 160 | 155 | 150 | 140 |
| 120                                      | 215                                         | 170 | 165 | 160 | 150 |

It can be seen from the table that, under the condition that the heating temperature of the old and new aggregate is constant, the discharge temperature of the recycled mixture decreases with the increase of the old material content. In addition, the technical specification for highway asphalt pavement recycling stipulates that the discharge temperature of the plant mixed hot recycled mixture should be 5 ~ 15 ℃ higher than that of the hot mix asphalt mixture, and the suitable discharge temperature of the hot mix asphalt mixture is obtained. The temperature should be 160 ~ 170 ℃. so it is difficult to meet the requirements when the RAP content is higher than 30%.

The research shows that adding appropriate amount of warm mixing agent in the mixture can not only reduce the mixing temperature required by the mixture, but also ensure that the performance of the mixture is close to or reach the conventional hot mix asphalt mixture. Therefore, this project proposes to add an appropriate amount of warm mixing agent in the recycled mixture to solve the problem that the discharge temperature of the recycled mixture is difficult to meet the requirements when the RAP content is higher than 30%.
5. **Study on the influence of water content of RAP on high content**

The high moisture content of old materials will not only affect the material composition and properties of recycled mixture, but also have a significant effect on the implementation of the whole regeneration process. The most important thing is that the discharging temperature of the whole recycled mixture will be significantly affected, thus greatly reducing the quality of recycled construction and the amount of milling material.

The high moisture content of RAP material directly affects the mixing efficiency and production cost of the mixture, so it must be strictly controlled in actual production. The results show that the specific heat capacity of water is 4182 J / (kg · °C) [3,4], which is 2.5 times of asphalt and 5 times of aggregate. At the same time, the vaporization heat of water is 2260 J / kg, which makes the water further take away a lot of heat when it reaches the boiling point. Therefore, RAP material with high water content will seriously affect the discharge temperature of mixture after mixing. In his paper, Hu Lin studied the influence of water content on the temperature of mixture. When the heating temperature of RAP and new aggregate is fixed, the temperature reduction value of recycled mixture with different RAP content was tested when the moisture content increased by 1%. The results show that, due to the existence of moisture in RAP material, the discharge temperature of recycled mixture decreases significantly, and with the increase of RAP proportion, the decrease of mixture discharge temperature increases. When RAP content reaches 30%, the moisture content increases by 1%, and the discharge temperature of mixture decreases by about 10 °C.

Combined with the research content in 4.1, it can be seen that when the RAP content reaches 40%, the water content is more than 2%, and the mixing plant is under the maximum power, the discharge temperature of the mixture is difficult to reach above 145 °C. Therefore, the influence of moisture content of RAP material should be considered in the design of high mixing hot recycled mixture. The dry RAP material should be used as far as possible, and its moisture content is no more than 2%. At the same time, in the actual production process, RAP materials should be strictly managed. RAP materials should be stacked on high and hard sites as far as possible, and measures such as canopy or covering should be adopted to do a good job of waterproof and drainage, and reduce the moisture content of RAP materials as far as possible.

6. **Conclusion**

The variation of RAP gradation in field milling rate and grading pretreatment shows that:

(1) The coefficient of variation of the passing rate of the slow milling is smaller than that of the fast milling, but the variation difference between the slow milling and the fast milling is not significant. It is suggested that the fast milling rate should be 5 ~ 7 m / min.

(2) According to the grading commissioning of the project, the medium grained asphalt mixture has a higher utilization rate of milling material than the coarse-grained asphalt mixture. Although the three grade preparation can reduce the variability of RAP, it has little effect on improving the utilization rate of RAP. Considering the gradation and filler-asphalt ratio (the filler-asphalt ratio of the project is controlled to be less than 1.3), the maximum RAP content of AC-25 asphalt mixtures is 50% according to the grading calculation curve.

(3) According to the grading calculation of the project, the empirical formula of coarse and fine aggregate mix is put forward to realize the balanced design of utilization and economy.

(4) Only considering the gradation range, the content of RAP can reach more than 70%. Considering the actual production, the limit content of milling material is restricted by RAP moisture content, filler-asphalt ratio, discharge temperature and warm mixing method. To sum up, the theoretical limit content of RAP is less than 60%.

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