The Optimization Design of Mixing Ratio of ARAC-13 Rubber Asphalt Mixture based on Low Temperature Crack Resistance

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Abstract. The representative ARAC-13 mineral grading range was calculated by power curve grading, combining with the climatic characteristics of Gannan high-altitude and damp areas. The gradation of five kinds of ARAC-13 rubber asphalt mixture was designed based on representative grading. Different grade rubber asphalt mixtures were studied by the freeze-thaw splitting test and low temperature bending test to optimize the mix design of ARAC-13 mixture.

1. Introduction
Rubber asphalt mixture is more and more widely used and wet rubber asphalt mixture often is used in the gradation design. The main problem of rubber asphalt mixture design is to choose the appropriate gradation to adapt to the large viscosity and containing a large number of rubber particles of rubber asphalt binder. ARAC structure and traditional AC structure mixture has a certain difference. The structure mixture of ARAC is a typical fault gradation mixture, closing to SMA, but isn’t SMA. Because ARAC rubber asphalt mixture does not need to add mineral powder.

Combined with the climate characteristics of Gannan high altitude and damp areas in Gansu province, the temperature variation of four seasons is greatly from morning to evening. In July the average daily temperature is 15 to 17 °C, and in January the average daily temperature is 7 °C below zero. In this area, the performance of asphalt pavement should be considered in climate zoning hot summer and wet area, winter low temperature and long duration. The key consideration in the design of ARAC - 13 mixture gradation is the performance in the low temperature crack resistance of rubber asphalt mixture.

2. Selection of representative gradation of rubber asphalt
At present, the rubber asphalt mixture usually takes the form of coarse aggregate gap grading, and forms a dense type of gap grading mixture. This kind of design concept needs to make sure the discontinuity point of mixture gradation. In order to compare with the common asphalt mixture and other modified asphalt mixture, the discontinuity point of coarse aggregate and fine aggregate in rubber asphalt mixture is usually located in the position of the 4.75mm. There's a coarse aggregate gradation curve from 4.75mm to the nominal maximum aggregate size of mineral aggregate gradation. There's a fine aggregate gradation curve from 0.075 mm to 4.75 mm. Each gradation curve can be fitted by curve model in different fitting forms. The commonly used fitting models include power function curve form, exponential curve form, logarithmic curve form, etc. The curve model formula is as follows:
By\( A \times e^{Bx} \)
\( y = A \times e^{Bx} \) \quad (2)
\( y = A \ln(x) - B \) \quad (3)

In the formula: \( x \) -- mesh diameter;
\( y \) -- pass rate;
\( A, B \) -- regression coefficient.

According to the existing research, under the same ratio of oilstone, the gradation of exponential model fitting is the coarsest, but the porosity is the smallest. The gradation of logarithmic model fitting is the finest gradation, but the porosity is the highest. The gradation of power curve model fitting is moderate. This shows that the power curve gradation fitting model can be used to give consideration to the uniformity and compactness of rubber asphalt mixture. According to the power function model, the composition of the intermittent gradation of ARAC-13 rubber asphalt mixture is preliminarily calculated. The pass rate of controlling the maximum nominal particle size 13.2mm is between 90\% and 100\%, taking about 95\%; The pass rate of discontinuity point 4.75mm is controlled as 30\%; The pass rate of 0.075mm was 7\%.

Equations for aggregates above 4.75mm were established[1]:
\[
\begin{align*}
A_1 \times 4.75^{B_1} &= 30\% \\
A_1 \times 13.2^{B_1} &= 95\%
\end{align*}
\]
Equations for aggregates under 4.75mm were established:
\[
\begin{align*}
A_2 \times 0.075^{B_2} &= 7\% \\
A_2 \times 4.75^{B_2} &= 30\%
\end{align*}
\]
Equations: \( A_1 = 5.176 \), \( A_2 = 17.367 \), \( B_1 = 1.128 \), \( B_2 = 0.351 \).

Thus, the model fitting equation of aggregate gradation is:
\[
y_{(4.75-13.2)} = 5.176x^{1.128} \quad (6)
\]
\[
y_{(0.075-4.75)} = 17.367x^{0.351} \quad (7)
\]

According to the above equation of aggregate grading curve model, the pass rate of different sieve pore diameters was calculated, and the representative grading curve was obtained. The results are shown in table 1.

| The size of olfactory foramina (mm) | 16 | 13.2 | 9.5 | 4.75 | 2.36 | 1.18 | 0.6 | 0.3 | 0.15 | 0.075 |
|-------------------------------------|----|------|-----|------|------|------|----|----|-----|-------|
| The pass rate of aggregate (%)      | 100| 95.0 | 65.6| 30.0 | 23.5 | 18.4 | 14.5| 11.4| 8.9  | 7.0   |

3. Gradation design and optimization
In order to meet the low temperature crack resistance of rubber asphalt mixture, the range of mixture should be as far as possible above the median of the recommended range. In the gradation, due to the small angular properties of aggregate in the range of 0.15 – 0.3mm and 0.3 – 0.6mm, it is not suitable to form friction resistance. Therefore, on the premise of meeting the gradation range, the aggregate within the range should be reduced as much as possible, so that the difference between the upper and lower limit of the pass rate of 4.75mm and 2.36mm is less than 10\%. Based on the representative gradation selected by calculation, the pass rate of 4.75mm was adjusted according to the increasing...
(decreasing) trend of 2%, and the pass rate of 2.36mm and 0.075mm sieve holes was taken into account. The five different gradation curves of ARAC-13 rubber asphalt mixtures were designed, and the results are shown in table 2.

### Table 2. The five different gradation curves of ARAC-13 rubber asphalt mixtures

| Gradation design | The percentage of mass through the following sieve holes (%) |
|------------------|-------------------------------------------------------------|
|                  | 16 13.2 9.5 4.75 2.36 1.18 0.6 0.3 0.15 0.075             |
| Gradation design 1 | 100 98 72 34 28.5 22 18 16 13 10                          |
| Gradation design 2 | 100 98 70.5 32 26.5 20 16 14 11 8                           |
| Gradation design 3 | 100 95 65.6 30 23.5 18.4 14.5 11.4 8.9 7                   |
| Gradation design 4 | 100 97 61 28 21.5 14.5 11 9 7 5                            |
| Gradation design 5 | 100 97 60 26 20 13.5 9.5 7.5 5 3                             |
| Lower limit of design interval | 100 95 60 25 20 13 9 7 5 3                                  |
| Upper limit of design interval | 100 100 72 35 28 23 19 15 14 10                             |

### 4. Freeze-thaw splitting and low-temperature performance test analysis of the mixture

According to the above five gradation curves, Marshall specimen of rubber asphalt mixture was formed by two-sided compacted for 75 times with the asphalt-aggregate ratio of 7.0%, 7.4%, 7.8%, 8.2% and 8.6%, respectively. According to the 5% void ratio, the optimum asphalt-aggregate ratio of different grades is obtained. Under the optimum asphalt-aggregate ratio, the specimen is formed and the freeze-thaw splitting test and the low-temperature bending test of mixture were carried out. The low-temperature bending test is tested under the condition of experiment of temperature - 10 °C and in 50 mm/min loading rate, the results are as follows in table 3.

### Table 3. The test results of ARAC-13 rubber asphalt mixture

| AR-AC-13 Gradation design | Asphalt-aggregate ratio (%) | Relative density of gross volume (%) | Voids in mineral aggregate (%) | Maximum load at failure of specimen Pa(N) | Mid-span deflection at failure d(mm) | Flexural-tensile strain εf (με) | TSR (%) |
|---------------------------|----------------------------|------------------------------------|-------------------------------|----------------------------------------|-----------------------------------|---------------------------------|---------|
| Gradation design 1        | 7.1                        | 2.483                              | 5                             | 17.7                                   | 1732.6                            | 0.958                           | 4943    | 86.6   |
| Gradation design 2        | 7.4                        | 2.475                              | 5                             | 18.0                                   | 1775.0                            | 1.093                           | 5940    | 89.2   |
| Gradation design 3        | 7.5                        | 2.471                              | 5                             | 18.1                                   | 1654.9                            | 1.204                           | 6357    | 88.4   |
| Gradation design 4        | 7.7                        | 2.460                              | 5                             | 18.5                                   | 1758.9                            | 1.036                           | 5625    | 86.9   |
| Gradation design 5        | 7.8                        | 2.454                              | 5                             | 18.7                                   | 1670.6                            | 0.885                           | 4898    | 83.2   |

From the above results, it can be seen that the freeze-thaw cycle strength ratio of rubber-asphalt mixture and the low-temperature bending performance of the ARAC-13 rubber asphalt mixture are excellent. The bending strain value ($\varepsilon_f$) is greater than 4500(με). For the five gradations selected, the bending strain value ($\varepsilon_f$) and freeze-thaw splitting tensile strength ratio (TSR) change with the gradation of several mixtures is as follows.
The figure shows that as the pass rate of the key mesh 4.75mm goes down, the aggregates graded from 1 to 5 gradually became thicker. From grade 1 to grade 3 range, the bending tensile strain values epsilon (ε_B) and freeze-thaw splitting tensile strength ratio (TSR) increased with the increase of coarse aggregate. From grade 3 to grade 5 range, the bending tensile strain values epsilon (ε_B) and freeze-thaw splitting tensile strength ratio (TSR) decreased with the increase of coarse aggregate. The selected gradation from gradation 1 to gradation 5 is basically a parabola (the correlation coefficients are all greater than 0.95), and the optimal gradation range is around gradation 3.

5. Conclusion
From the above analysis, it can be seen that the performance of ARAC-13 rubber asphalt mixture with the above five gradations can meet the requirements of the hot summer and cold winter humid climate environment in Gannan plateau after freeze-thaw cycle splitting test and low-temperature bending test. Considering the low temperature days many parts of the annual average days and the characteristics of the rubber asphalt, and selecting 5% porosity and the 7.0% asphalt-aggregate ratio for gradation design, recommend that applies to Gannan plateau area of rubber asphalt pavement of high grade highway ARAC - 13 mixture of engineering design gradation scope. As shown in table 4.
Table 4. The recommended ARAC-13 rubber asphalt mixture design gradation range

| ARAC-13 Optimized design gradation | The percentage of mass through the following sieve holes (%) |
|-----------------------------------|----------------------------------------------------------|
| Lower limit of design gradation   | 16 13.2 9.5 4.75 2.36 1.18 0.6 0.3 0.15 0.075          |
| Upper limit of design gradation   | 100 95 60 26 20 13.5 9.5 7.5 5 3.5                     |

The optimization design of ARAC - 13 rubber asphalt mixture is an s-shaped curve in the grading of both lower limit of design gradation and upper limit of design gradation. The rubber asphalt mixture can be ensured to form a skeleton - compact structure with 4.75 mm as the discontinuity point, and make the ARAC-13 rubber asphalt mixture have suitable porosity, low permeability, low temperature and good water stability. The surface of the ARAC-13 rubber asphalt also has a greater depth of structure, meeting the driving requirements.

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