The SMC Normal Temperature Reclaimed Asphalt Mixture Mix Design and Performance Evaluation Research

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Abstract. The SMC normal temperature reclaimed asphalt pavement (SMC-RAP) technology is a new kind of pavement regeneration technology, which could raise the usage of the reclaimed materials from the old road up to 60%, and would bring a significant economic and environmental benefits to the society. The mix design method and road performance evaluation of this new material has been researched by this paper.

Introduction

Recycling technology of asphalt pavement materials makes waste materials reusable in road paving, and it would significantly reduce the cost of highway construction. At present, the hot mix plant recycling technology is considered to have the best using effect among the asphalt pavement regeneration methods. However, higher product temperature is required by this technique, and the usage rate of the reclaimed asphalt pavement (RAP) is regulated less than 30% by the national specification, which all have restricted the application of the technology.

The SMC normal temperature reclaimed asphalt pavement (SMC-RAP) technology is researched by this paper. It greatly decreased the mixing temperature of the asphalt mixture, and reduced the product temperature up over 30°C compared with the traditionally applied ones. It could effectively avoids the second-time aging in the process of regeneration. Through apply the SMC-RAP in the test road, the usage rate of the RAP has reached more than 60%, and the road performance is still satisfied.

The asphalt pavement recycling technology has been significant boosted by the research of this paper. The SMC-RAP technique is coincidence to the policy of building green transportations in China, and would bring desirable social and economic benefits to the industry.

Mix Design of the SMC Normal Temperature Reclaimed Asphalt Mixture

Raw Materials

The SBS I-C modified asphalt and limestone broken stone were used in the test road, and their test results conformed to the national specification requirements, tests results are shown from Table1 to Table 3.

| Aggregate       | Technical Requirements of Apparent Relative Density | Apparent Relative Density | Apparent Density \( [g/cm^3] \) | Relative Density of Bulk Volume | Water Absorption \( [%] \) |
|-----------------|-----------------------------------------------------|---------------------------|---------------------------------|--------------------------------|--------------------------|
| [16-22]mm Breakstone | \( \geq 2.45 \)                                      | 2.717                     | 2.712                           | 2.673                          | 0.62                     |
| [11-16]mm Breakstone  | \( \geq 2.45 \)                                      | 2.722                     | 2.717                           | 2.664                          | 0.80                     |
| [0-3]mm Aggregate Chips | \( \geq 2.45 \)                                      | 2.709                     | 2.704                           | 2.645                          | 1.54                     |
Table 2. Technical requirements and testing results of aggregate.

| Item                          | Unit | Requirements | Test Result |
|-------------------------------|------|--------------|-------------|
| Crushing Value                | %    | ≤30          | 17.7        |
| Los Angeles Abrasion Loss     | %    | ≤35          | 18.7        |
| Soft Rock Content             | %    | ≤5           | 1.8         |
| Adhesion of Aggregate to Asphalt | grade | ≥3        | 4           |
| Sand Equivalent               | %    | ≥50          | 62          |
| Needle and Flaky Particle Content | %    | ≤20          | 5.5         |

Table 3. Technical requirements and testing results of the modified asphalt SBS I-C.

| Item                                      | Unit                  | Requirements       | Test Result |
|-------------------------------------------|-----------------------|--------------------|-------------|
| Needle Penetration (25℃, 5s, 100g)       | 0.1mm                 | 80~100             | 86          |
| Needle Penetration Index (PI)             | /                     | -1.5~+1.0          | -0.6        |
| 10℃ Ductility                             | cm                    | ≥30                | 72          |
| 15℃ Ductility                             | cm                    | ≥100               | >100        |
| Softening Point (R&B)                     | ºC                    | ≥44                | 46.5        |
| 60℃ Dynamic Viscosity                    | Pa.s                  | ≥140               | 275         |
| Wax Content (Distillation)                | %                     | ≤2.2               | 1.7         |
| Flash Point                               | ºC                    | ≥245               | 286         |
| Solubility                                | %                     | ≥99.5              | 99.70       |
| Density (15℃)                             | g/cm³                 | Actual Observation Record | 0.983 |
| TFOT (163℃, 5h)                           |                       | Quality Change     | 40.8        |
|                                           |                       | Residual Needle Penetration Ratio | ≥57         |
|                                           |                       | Residual Ductility  | ≥8          |

**Type of the Aggregate Gradation**

Reference to the gradation range of the AC-16 set from the national specification, the gradations conforming to the standard range for the SMC-RAP has been work out. The ratio of RAP were 60%. Sieving results of various aggregates are shown in Table 4, and the gradation curve is shown in Figure 1.

Table 4. Mineral proportion and synthetic gradation.

| Aggregate Size | [10-20]mm Breakstone | [10-15]mm Breakstone | [0-3]mm Breakstone | RAP | Synthetic Gradation | Gradation Range |
|----------------|----------------------|----------------------|--------------------|-----|---------------------|-----------------|
| Sieve Size[mm] | 10                   | 20                   | 10                 | 60  |                     |                 |
| 19.0           | 93.4                 | 100.0                | 100.0              | 100.0 | 99.3 | 100 |
| 16.0           | 37.8                 | 100.0                | 100.0              | 99.3 | 93.4 | 90-100 |
| 13.2           | 1.6                  | 74.9                 | 100.0              | 95.3 | 82.3 | 76-92 |
| 9.5            | 0.2                  | 16.0                 | 100.0              | 79.7 | 61.0 | 60-80 |
| 4.75           | 0.1                  | 0.4                  | 99.8               | 49.8 | 40.0 | 34-62 |
| 2.36           | 0.1                  | 0.4                  | 84.6               | 31.6 | 27.5 | 20-48 |
| 1.18           | 0.1                  | 0.4                  | 62.2               | 23.5 | 20.4 | 13-36 |
| 0.60           | 0.1                  | 0.4                  | 42.5               | 18.3 | 15.3 | 9-26 |
| 0.30           | 0.1                  | 0.4                  | 30.7               | 13.8 | 11.4 | 7-18 |
| 0.15           | 0.1                  | 0.4                  | 17.8               | 10.9 | 8.4  | 5-14 |
| 0.075          | 0.1                  | 0.4                  | 5.3                | 8.6  | 5.8  | 4-8  |
Determination of the Optimum Asphalt Aggregate Ratio

The test road is a national secondary level road, located near the Hohhot city, Inner Mongolia, where the climate is belong to the summer hot winter cold semi dry area.

As the average asphalt content of the reclaimed asphalt mixture was 3.8%, and the recycling rate of the RAP was 60%, then, the asphalt content of the new and old mixtures was 2.33%. Assume the optimum asphalt aggregate ratio was 4.6%, the new adding asphalt could be calculated as 2.17%. Set the assumed the optimum ratio 4.6% as the median value, addition and subtraction 0.4% from that value, then 5 results of the optimum asphalt aggregate ratio (3.8%, 4.2%, 4.6%, 5.0%, 5.4%) could be obtained. The corresponding new adding asphalt amount was (1.41%, 1.79%, 2.17%, 2.54%, 2.91%).

According to the national specification to conduct the Marshall compaction test and maximum theoretical density test, pre-designed void volume (VV) was 4.5%.

When forming the test specimen, the preheating temperature of the reclaimed materials was 100-110°C, preheating for 2h; the heating temperature of the new adding materials was 140°C, heating for 4h. Asphalt heating temperature was controlled as 130°C-140°C, and mixing temperature for the mixture was controlled as 130-140°C. When conduct the mixing, put the preheating new and reclaimed materials together into the mix pot, after mix for 120s, put the asphalt, continually mixed for 300s, which was 120s longer than the standard mixing time. The compaction temperature was 130-140°C, compacted 100 times for each side of the specimen. After mold unloading of the specimen, curing for 3d at the room temperature. The test results are shown in Table 5.

Table 5. Summary of the Marshall test results.

| Asphalt Aggregate Ratio[%] | Maximum Relative Density Measured by Vacuum Method | Measured Relative Density | VV [%] | VMA [%] | VFA [%] | MS [kN] | FL [mm] |
|----------------------------|---------------------------------------------------|---------------------------|--------|--------|--------|---------|--------|
| 3.8                        | 2.538                                             | 2.379                     | 6.3    | 14.7   | 57.3   | 9.94    | 2.60   |
| 4.2                        | 2.525                                             | 2.387                     | 5.5    | 14.8   | 63.1   | 10.68   | 2.73   |
| 4.6                        | 2.510                                             | 2.400                     | 4.4    | 14.6   | 70.1   | 11.02   | 3.20   |
| 5.0                        | 2.496                                             | 2.400                     | 3.9    | 15.0   | 74.3   | 10.58   | 3.47   |
| 5.4                        | 2.483                                             | 2.392                     | 3.7    | 15.5   | 76.4   | 10.14   | 3.71   |
| Technical Requirement     | /                                                 | /                         | 3-6    | /      | 65-75  | ≥ 5     | 2-4.5  |
According to the results in Table 5 and the calculation method of the asphalt aggregate ratio from the national specification, the optimum asphalt aggregate ratio was finally determined as 4.7%.

Conduct the Marshall test to the specimen under the optimum asphalt aggregate ratio, all indicators has met the requirements of the standard, the test results are shown in Table 6.

Table 6. Summary of the Marshall test results under the optimum asphalt aggregate ratio.

| Relative Density of Synthetic Bulk Volume | 2.687 | Maximum Theoretical Relative Density | 2.506 |
|------------------------------------------|-------|-------------------------------------|-------|
| Effective Asphalt Content                | 4.46  | Powder Binder Ratio of the Asphalt Mixture | 1.3   |
| Asphalt Aggregate Ratio [%]             | 4.7   | Measured Relative Density            | 2.398 |
| VV [%]                                  | 4.3   | VMA [%]                              | 14.8  |
| VFA [%]                                 | 70.7  | MS [kN]                              | 10.8  |
| FL [mm]                                 | 3.2   |                                     |       |

Road Performance Test of the SMC Normal Temperature Reclaimed Asphalt Mixture

After paving the test road, the high temperature performance, water stability and water seepage tests were conducted to assess the road performance of the SMC-RAP road. All indicators has meet the requirements of the standard, the test results are shown in Table 7.

Table 7. Road performance summary table for the SMC-16 RAP test road.

| High Temperature Performance | Rutting Test | Dynamic Stability [times/mm] | 4086 |
|------------------------------|--------------|-------------------------------|------|
|                              | Immersion Marshall Test | Residual Stability [%] | 103  |
|                              | Freeze-thaw Splitting Test | Technical Requirement [%] | ≥75  |
| Water Stability              |                           | Residual Strength Ratio [%] | 90   |
|                              | Water Seepage Test | Technical Requirement [%] | ≥70  |
| Water Seepage Coefficient    |                           |                             |      |
|                              | Water Seepage Test | Water Seepage Coefficient [mL/min] | 104  |
|                              |                          | Technical Requirement [mL/min] | ≤120 |

Summary

(1) The mixing and compaction temperature of the SMC normal temperature reclaimed asphalt mixture is 130-140°C, which decreases over 30°C compared with the traditional RAP ones, and effectively avoids the asphalt second-time aging in the process of regeneration.

(2) The application of the SMC-RAP has been raised up to 60% in the test road, which has significantly promoted the usage of the reclaimed materials.

(3) The mix design method of the SMC-RAP was same with the commonly used RAP in the test road, under the optimum asphalt aggregate ratio, the high temperature performance, water stability and water seepage tests results could meet the requirements of the national specification.

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