Effects of Aggregate Gradation on Drying Micro-Surfacing added by Waste Rubber Powders

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Abstract. In order to research the effects of aggregate gradation on micro-surfacing, the control variable method was used, the effects of different aggregate gradation on drying micro-surfacing added by waste rubber powders were studied, through a series of laboratory testing, indexes such as mixing time, cohesion torque, wet track abrasion value, load wheel value were studied. The results showed that intermediate gradation with 10% and 11% of the bitumen-aggregate ratio had the optimal performance. The mixing time and cohesion torque could all meet specification requirements; its anti-wear value and the adhering sand amount were smaller than conventional. So the micro-surfacing layer should form the internal compact, but also the formation of rough surface.

1. Introduction
The rubber powder dry micro-surfacing had significantly effect on anti-cracking, anti-wear, anti-fatigue, driving comfort and other performances. However, the quality of material was good, after paved still there were lots of problems in micro-surfacing. The practice showed that aggregate gradation had great effects on mix performance of micro-surfacing. Therefore, in order to ensure the quality of the material used in the micro-surfacing, it was very important to select a suitable gradation to match the quality of the micro-surfacing.

2. Experiment material
2.1. Modified emulsified asphalt
Test used SBR modified emulsified asphalt, its technical parameters were satisfied with the specification of micro-surfacing and slurry seal technology guide [1, 2], the test results were shown in Table 1.

| Pilot projects                      | Technical requirements | Test results | Experiment method |
|-------------------------------------|------------------------|--------------|-------------------|
| Demulsification rate                | Slow breaking          | Slow breaking| T0658             |
| The remaining amount on the sieve   | ≤0.1                   | 0            | T0652             |
| (1.18mm)/%                          |                        |              |                   |
| Electric charge                     | Cation+                | Cation+      | T0653             |
2.2. Aggregate
The test aggregates were basalt, with a small particle size of more than 9.5 mm, which had been sieved before the test [3]. The main technical indicators were shown in Table 2 [4].

| Evaporation residue properties | Penetration (25°C,100g,5s)/0.1mm | 40~100 | 88 | T0604 |
| Evaporation residue content/% | ≥60 | 62.5 | T0651 |
| Ductility (5°C)/cm | ≥20 | 80 | T0605 |
| Softening point/°C | ≥53 | 56 | T0606 |
| Solubility (trichlorethylene)/% | ≥97.5 | 99 | T0607 |

Table 2. Aggregate technical properties and test results.

| Pilot projects | Technical requirements | Test results | Experimental method |
|----------------|------------------------|--------------|---------------------|
| Coarse aggregate | Stone crushing value/% | ≤26 | 12 | T0316 |
| Los Angeles wear loss/% | ≤28 | 13.6 | T0317 |
| Stone polished value/BPN | ≥42 | 46 | T0321 |
| Ruggedness /% | ≤12 | 0.9 | T0314 |
| Ruggedness /% | ≤15 | 0.5 | T0312 |
| Synthetic mineral sand equivalent/% | ≥65 | 69.5 | T0334 |

2.3. Filling
Filling mainly cement and waste rubber powder. The cement used in this test was an ordinary portland cement without any additives, cement strength of 42.5, the amount of 1.5% (with the mass ratio of aggregate). The waste rubber used in this test was 40 mesh, the amount of 1% (with the mass ratio).

2.4. Water
The amount of water should be minimized when the requirements were met. The test used drinking water, and the content of water was 6% [1].

3. Performance of micro-surfacing
3.1. Mineral aggregate gradation
According to the International Slurry Seal Association's design method, the MS-3 gradation was required to mix. According to the sieving results of aggregates, coarse, intermediate and fine gradations were designed, as was shown in Table 3[3-5].
Table 3. Aggregate gradation table.

| Gradation type | Percentage of mass by the following sieve (mm)% |
|----------------|-----------------------------------------------|
|                | 9.5   | 4.75 | 2.36 | 1.18 | 0.6  | 0.3  | 0.15 | 0.075 |
| 5-10mm         | 100.0 | 9.7  | 2.0  | 1.9  | 1.9  | 1.8  | 1.8  | 1.7   |
| 3-5mm          | 100.0 | 93.8 | 3.4  | 1.5  | 0.9  | 0.8  | 0.7  | 0.7   |
| 0-3mm          | 100.0 | 100.0| 77.8 | 57.9 | 42.6 | 29.0 | 20.9 | 15.1  |
| Fine gradation | 100.0 | 88.6 | 62.0 | 46.1 | 34.0 | 23.2 | 16.8 | 12.2  |
| Intermediate grade | 100.0 | 80.4 | 53.7 | 40.0 | 29.5 | 20.2 | 14.7 | 10.7  |
| Coarse gradation | 100.0 | 73.8 | 45.4 | 33.8 | 25.0 | 17.1 | 12.5 | 9.2   |

3.2. Mixing test

Through a large number of tests, the best ratio of the three mixes was determined as the aggregate: cement: waste rubber powder: water: modified emulsified asphalt = 100: 1.5: 1: 6: 14.4. The test results were shown in Table 4.

3.3. Cohesion torque test

The cohesion test was carried out using the same mixing ratio as the mixing test, the test results were shown in Table 4.

Table 4. Results of mixing time and cohesion test.

| Gradation type | Mixing time/s | Non-construction time/s | 30min Cohesion torque/(N•m) | 60min Cohesion torque/(N•m) |
|----------------|---------------|-------------------------|-----------------------------|-----------------------------|
| Coarse         | >180          | 350                     | 1.3                         | 2.0                         |
| Intermediate   | 140           | 300                     | 1.6                         | 2.3                         |
| Fine           | 135           | 240                     | 1.8                         | 2.3                         |

It could be seen from Table 4, the mix of coarse gradation mixing time was the longest. Intermediate gradation was 140s, fine gradation with the shortest mixing time. Not the construction time was the same law in descending order. Mainly because the intermediate and fine with the powder more, absorbed moisture and emulsified asphalt emulsion, at the same pitch ratio and the amount of water used, the mixture was thicker than the coarse gradate mix, mixing time and no construction time was not long. As could be seen from table 4, coarse grading of 30min and 60min cohesion value of the smallest, the cohesion of the intermediate with 60 min cohesive force had no aggregate dissolution and good effect. The main reason for the difference was that the coarse gradation of the fine aggregate was less; the indenter was slipped on the surface of the specimen so that the cohesive force was too small. And intermediate and fine with the mixture in the powder more, could filled the gap between the coarse aggregate, so the specimen was not damaged and cohesion value to meet the requirements [6-8].

3.4. Wet track abrasion test and load wheel test

Wet track abrasion test used the same mixing ratio as the cohesion test; the load wheel test was still the same mixing ratio as the cohesion test, the test results were shown in Table 5.
Table 5. Results of wet track abrasion test and load wheel test.

| Gradation type | Asphalt-aggregate ratio/% | Wear value 1h(g/m²) | Wear value 6d(g/m²) | Adhesive sand content(g/m²) |
|----------------|---------------------------|----------------------|---------------------|----------------------------|
| Coarse         | 9                         | 428                  | 545                 | 310                        |
|                | 10                        | 457                  | 694                 | 397                        |
|                | 11                        | 643                  | 806                 | 680                        |
| Intermediate   | 9                         | 1108                 | 1257                | 208                        |
|                | 10                        | 280                  | 490                 | 274                        |
|                | 11                        | 291                  | 301                 | 390                        |
| Fine           | 9                         | 1204                 | 1637                | 179                        |
|                | 10                        | 418                  | 1269                | 266                        |
|                | 11                        | 467                  | 525                 | 284                        |

It could be seen from Table 5, in the wet track abrasion test, the intermediate aggregate with 10% and 11% asphalt-aggregate ratio when the wear value was small, asphalt and mineral filler and wear resistance of the best, this was because the number of medium-sized mineral material in the powder could just fill the gap between the coarse aggregate, and powder and rubber powder together could absorb the excess moisture and asphalt emulsion, moreover, made the inside of the specimen after the more compact, to form a whole; while the intermediate level with 9% of the asphalt-aggregate ratio, the measured wear value was large, beyond the provisions of the range, this was because the middle with more powder, made the material than the surface area, and the rubber powder adsorption emulsified asphalt was very strong, coupled with low than the asphalt-aggregate ratio, in the three under the combined effect of the formation of the specimen asphalt film thickness was small, so wear loss was great[6-10].

4. Conclusions
(1) The wear value of coarse gradation was more than specifications whether high asphalt-aggregate ratio or not, under the condition of certain asphalt-aggregate ratio, the values of cohesion of fine and intermediate gradation were larger than coarse gradation, it helped to be open to traffic quickly.
(2) The aggregate powder was filled in the gap of the coarse aggregate skeleton; excess water and asphalt emulsion were absorbed by aggregate powder and rubber powder, micro-surfacing mixtures after paving had good wear resistance and water stability.
(3) Wet abrasion test and adhesion test results showed that when asphalt-aggregate ratio was 10% or 11%, the performance of intermediate gradation of MS-3 micro-surfacing was the best.

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