Effect of Grading Type on the Performance of Warm-Mix Rubber-Asphalt Mixture

Zhang Qiang
GuangDong construction vocational technology institute, Guangzhou, Guangdong, 510440, China
Corresponding author’s e-mail: 654746715@qq.com

Abstract. This paper designs three warm-mix rubber-asphalt mixtures with different grading types based on the Course Aggregate Void Filling method (CAVF) and standard method, and studies the rules of influence of the warm mixing effect and grading type of the warm-mix rubber-asphalt on the pavement performance of the mixtures through compaction temperature analysis, Marshall test, and rutting test. The results show that the compaction temperature of warm-mix rubber-asphalt mixture can be reduced by about 20 ℃, and it has a significant warm mixing effect and excellent pavement performance.

1. Introduction
The rubber asphalt modified by waste tire rubber powder has excellent performances. When it is used for paving the road surface, it shows good pavement performance as well as satisfactory noise reduction, anti-slip and wear-resistant performance, without such problems as rutting, upheaval, shifting, or flushing [1]. However, the rubber-asphalt mixture requires a high construction temperature and a lot of energy. In addition, it is necessary to pay attention to the exhaust gas and dust generated during the construction process as well as the asphalt aging problem due to long-term high-temperature mixing.

The application of warm mixing technology can help to handle the above-mentioned problems caused by the high temperature. Studies have shown that the Wax WMA method in warm mixing technology can effectively reduce the high-temperature viscosity of asphalt, but has no effect on its low-temperature viscosity. In this way, it can help to achieve the effect of reducing construction temperature [2].

The warm-mix rubber asphalt used in this paper is modified by the organic viscosity-reducing agent called Sasobit. The performance of rubber asphalt will change after the agent is added. This paper designs three warm-mix rubber-asphalt mixtures with different grading types based on the Coarse Aggregate Void Filling method (CAVF) and standard method, and comprehensively studies the pavement performance of the mixtures through Marshall test, rutting test, and freeze-thaw splitting test.

2. Raw material

2.1. Rubber asphalt
The rubber asphalt used in this paper is Esso AH-70 asphalt mixed with 18% waste tire rubber powder. It is prepared through high-speed shearing and chemical development reaction at a high temperature (about 180 °C) by using the German FULUC high-speed shear mixer. Its performance is shown in Table 1. It can be seen that its performance indexes not only meet the relevant requirements of “Technical Specifications for Highway Asphalt Pavement Construction” (JTG F40-2004), but also reach PG88-28
according to the American Superpave asphalt performance classification standard [3], showing good high-and low-temperature performances.

### Table 1. Rubber asphalt performance indicators

| Technical indicators | Unit     | Test results | Test methods         |
|----------------------|----------|--------------|----------------------|
| Penetration 25℃, 100g, 5s | 0.1mm | 37 | T 0604-2011 |
| Softening point TR&B | °C | 65.5 | T 0606-2011 |
| Ductility (15℃) | cm | 8.7 | T 0605-2011 |
| Elastic recovery 25℃ | % | 80.9 | T 0662-2011 |
| Rotational viscosity 190℃ | Pa·S | 2.55 | T 0625-2011 |

- Original rubber asphalt
  - Dynamic shear, G*/sinδ, @10rad/s, 76℃ kPa: 7.03
  - Dynamic shear, G*/sinδ, @10rad/s, 82℃ kPa: 4.95
  - Dynamic shear, G*/sinδ, @10rad/s, 88℃ kPa: 4.09

- Residue after RTFOT 163 ℃, 85min
  - Dynamic shear, G*/sinδ, @10rad/s, 76℃ kPa: 14.37
  - Dynamic shear, G*/sinδ, @10rad/s, 82℃ kPa: 10.70
  - Dynamic shear, G*/sinδ, @10rad/s, 88℃ kPa: 8.04

- Residue after PAV 100 ℃, 20h
  - Dynamic shear, G*/sinδ, @10rad/s, 76℃ kPa: 170.23
  - Dynamic shear, G*/sinδ, @10rad/s, 82℃ kPa: 954.57
  - Dynamic shear, G*/sinδ, @10rad/s, 88℃ kPa: 1455.3

- Creep stiffness, @60s, -18℃ S MPa: 186
  - m value: 0.356

- Creep stiffness, @60s, -24℃ S MPa: 391
  - m value: 0.241

---

### 2.2. Organic viscosity reducer

Sasobit warm-mix modifier made by Schümann-Sasol Company is used as the organic viscosity reducer. Its performance is shown in Table 2. Sasobit’s melting point is 103 ℃ and it is completely soluble in asphalt at 115 ℃, requiring simple mechanical stirring techniques for it to be dissolved in asphalt without dissociation [4].

### Table 2. The performance of Sasobit warm mix modifier

| Melting point (℃) | Flash point (℃) | 135°C viscosity (cp) | 25°C penetration (0.1mm) | 65°C penetration (0.1mm) | 25°C density (g/cm³) |
|------------------|----------------|----------------------|-------------------------|-------------------------|---------------------|
| 103              | 290            | 12                   | <1                      | 7                       | 0.94                |

---

### 2.3. Warm-mix rubber asphalt

The process of warm-mix rubber asphalt is: mix 3% Sasobit into the rubber asphalt prepared using the above method when it is heated to 115 ℃; stir it using a mixer for 20 minutes; cast pouring. The performance indexes are shown in Table 3. From Table 1 and Table 3, it can be seen that the softening point of the material is improved, but the flexibility is reduced after mixing Sasobit.

### Table 3. The performance of Warm Mix Asphalt Rubber

| Technical indicators | Unit     | Test results |
|----------------------|----------|--------------|
| Penetration 25℃, 100g, 5s | 0.1mm | 33 |
| Softening point TR&B | °C | 87 |
| Ductility (15℃) | cm | 6.9 |
| Elastic recovery 25℃ | % | 72 |
3. Grading design
Due to the existence of about 20% rubber powder in warm-mix rubber asphalt, the asphalt-aggregate ratio is usually relatively large, requiring proper design to ensure the formation of a dense skeleton structure, guarantee high-temperature performance, and to avoid rutting. The relevant domestic design codes lack the content related to the grading design method for warm-mix rubber asphalt and rubber-asphalt mixture. Therefore, this paper designs the warm-mix rubber-asphalt mixture (WRAC-13) based on the CAVF method. Two other gradations were designed according to the median of the specification, namely, SMA-13 with dense skeleton and AC-13 with dense suspension for the comparison purpose, as shown in Figure 1.

![Figure 1. The Design grading](image)

This paper designs the warm-mix rubber-asphalt mixture and rubber-asphalt mixture based on the aforementioned three grading methods to investigate the performance change of warm-mix rubber-asphalt mixture after adding the warm-mixing agent. The optimal asphalt dosage of the three mixtures is determined according to the current standard method [5], as shown in Table 4.

| Warm-mix rubber-asphalt mixture | Asphalt-aggregate ratio (%) | Rubber-asphalt mixture | Asphalt-aggregate ratio (%) | Grading design method |
|---------------------------------|-----------------------------|------------------------|-----------------------------|-----------------------|
| WRAC-13                         | 7.2                         | RAC-13                 | 7.1                         | CAVF method           |
| WRAC-SMA13                      | 6.9                         | RAC-SMA13              | 6.9                         | SMA13median           |
| WRAC-AC13                       | 7.5                         | RAC-AC13               | 7.4                         | AC-13median           |

It can be seen from Table 4 that both the warm-mix rubber-asphalt mixture and the rubber-asphalt mixture have an asphalt-aggregate ratio greater than that of the ordinary modified asphalt mixture, which is mainly due to the less content of effective asphalt in the two mixtures. More asphalt is needed to achieve the same cementing effect.

4. Pavement performance of warm-mix rubber-asphalt mixture

4.1. Compaction temperature of warm-mix rubber-asphalt mixture
The mixing and compaction temperatures of ordinary asphalt mixtures determined by the viscosity-temperature curve are often relatively higher. In this paper, the bulk density and porosity of the asphalt mixture at different temperatures are tested to determine the optimal temperature at which the maximum bulk density is reached.

The rubber-asphalt mixture (RAC-13) and the warm-mix rubber-asphalt mixture (WRAC-13) designed based on the CAVF method are taken as the samples to test the gross bulk density and porosity at different temperatures. The test results are shown in Figures 2 and 3.
It can be seen from Figure 2 that the temperature at which WRAC-13's gross bulk density reaches its maximum is 150 °C, and at this point, the porosity is about 4%. If 4% is used as the designed porosity, WRAC-13 can be compacted at the temperature 20 ℃ lower than RAC-13, thereby saving a lot of energy, alleviating the aging of asphalt caused by high temperature, and showing significant warm-mixing effect.

4.2. High-temperature performance
The Marshall test piece is formed based on the above gradating methods and the optimal amount of asphalt. The Marshall test is carried out according to the specifications at the temperature of 60 °C. The results are shown in Table 5.

| Asphalt Mixture Type | Bulk density (g/cm³) | VMA (%) | VFA (%) | Stability (kN) | Flow value (0.1mm) |
|----------------------|---------------------|---------|---------|----------------|-------------------|
| WRAC-13              | 2.367               | 20.0    | 0.775   | 14.7           | 26                |
| WRAC-SMA13           | 2.358               | 20.3    | 0.779   | 7.1            | 34                |
| WRAC-AC13            | 2.432               | 17.8    | 0.748   | 10.3           | 28                |
| RAC-13               | 2.378               | 19.7    | 0.771   | 13.8           | 26                |
| RAC-SMA13            | 2.363               | 20.2    | 0.777   | 6.8            | 38                |
| RAC-AC13             | 2.409               | 18.6    | 0.758   | 9.7            | 31                |

According to Table 5, all indexes of the three warm-mix rubber-asphalt mixtures meet the requirements of pavement construction specifications. In terms of strength, the WRAC-13 is the most
stable one with the smallest flow value. The mixture designed based on the CAVF method is stronger than that of AC asphalt mixture and SMA asphalt mixture based on the standard gradation.

The specimens used for the rutting test are maintained according to the standard method. The test temperature is 60 °C, the forming temperature of the warm-mix rubber-asphalt mixture is 140 °C, and the rubber asphalt mixture is still at 170 °C. The test results are shown in Figure 4.

![Figure 4. Rutting Test Results](image)

According to Figure 4, for warm-mix and hot-mix mixtures, the strength order of dynamic stability is: mixture using CAVF method > SMA asphalt mixture using standard grading > AC asphalt mixture using standard grading. Warm-mix rubber-asphalt mixture made based on the CAVF method is stronger than the SMA graded warm-mix rubber-asphalt mixture with the same dense framework; while AC graded warm-mix rubber-asphalt mixture and rubber asphalt mixture are significantly weaker, indicating that the dense suspension structure of AC grading is not suitable for warm-mix rubber-asphalt mixture.

Based on the results of Marshall test and rutting test, we can see that WRAC-13 designed based on CAVF method has good high-temperature stability and strong anti-rutting ability.

### 4.3. Water stability

In this paper, the Immersion Marshall test and freeze-thaw split test are used to comprehensively evaluate the water stability of warm-mix rubber-asphalt mixture. The results are shown in Table 6.

| Asphalt Mixture Type | Stability (kN) | Immersion residual stability (%) | Splitting tensile strength (MPa) | Freeze-thaw splitting strength ratio (%) |
|----------------------|----------------|----------------------------------|---------------------------------|----------------------------------------|
| WRAC-13              | 14.7           | 94                               | 0.98                            | 88                                     |
| WRAC-SMA13           | 7.1            | 6.3                              | 0.89                            | 85                                     |
| WRAC-AC13            | 10.3           | 86                               | 0.82                            | 82                                     |
| RAC-13               | 13.8           | 93                               | 0.92                            | 82                                     |
| RAC-SMA13            | 9.7            | 87                               | 0.87                            | 81                                     |
| RAC-AC13             | 6.8            | 87                               | 0.87                            | 81                                     |

According to Table 6, the warm-mix and hot-mix rubber-asphalt mixtures designed based on the CAVF method have the strongest resistance to water damage, followed by that made based on SMA and AC gradating methods. The warm-mix agent helps to increase the softening point of rubber asphalt and thus improve the strength of the mixture. However, it has no obvious effect on water stability. The results of the Immersion Marshall test and the freeze-thaw split test also show that the dense suspension is not suitable for warm-mix rubber asphalt mixture because it is likely to cause suspension structure.

Based on the results of the two tests, it can be seen that the WRAC-13 designed based on the CAVF method has good water stability and strong resistance to water damage.
5. Conclusion
This paper designs three warm-mix rubber-asphalt mixtures with different grading types based on the Coarse Aggregate Void Filling method (CAVF) and standard method and carries out compaction temperature analysis, Marshall test, and rutting test. The conclusion is as follows:

(1) The mixture designed based on the CAVF method has the best pavement performance; RAC-13 has good high temperature stability, strong anti-rutting ability, excellent water stability, and strong resistance to water damage.

(2) The CAVF method is suitable for the design of warm-mix rubber-asphalt mixture because it is in line with the characteristics of this material and can effectively help to form a dense skeleton structure. This method can be used to produce the SMA asphalt mixture with better pavement performances than that with the same dense skeleton structure.

(3) The compaction temperature of the warm-mix rubber-asphalt mixture mixed with Sasobit can be about 20 °C lower than that of the hot-mix rubber-asphalt mixture. The warm-mixing effect of the mixture is obvious, and its road performance is excellent, thereby boasting a broad application prospect.

Acknowledgments
This article was financially supported by the Guangdong Natural Science Foundation (Grant NO.2014A030310272).

References
[1] Zhang, X.Y, Xu,C. J. (2004) A review of the study on asphalt modified by waste rubber powder. Petroleum Asphalt, 4: 1–5.
[2] Wu, K.H,Wang,W.M. (2012) Pavement structure and material composition design of rubber asphalt test section of Xingyu Expressway. Journal of China & Foreign Highway , 6: 90–95.
[3] Lu, X.M, Zhou, J. (2006) Technical characteristics and application of new functional asphalt mixture. Petroleum Asphalt, 3: 52–57.
[4] Zhang, X.N, Wang, S. H.(2001) The CAVF method of asphalt mixture composition design. Highway, 12: 17–20.
[5] Xia,Y,Zeng,M.L.(2009)Experimental study on road performance of warm mix asphalt mixture with Sasobit. Highway Engineering,2:22-26