Study on Gradation and Performance of Cold Patch Asphalt Mixtures

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Abstract—In this paper, SMA-13 and LB-13 gradations are designed in order to study the influence of cold patch asphalt mixture gradation and the component changes of cold patch asphalt liquid on the performance of cold patch asphalt mixture. By measuring the volume parameters and Marshall stability of the two asphalt mixtures, the gradations are compared and analyzed. By measuring the Marshall stability and residual stability of LB-13 cold patch asphalt mixture with different anti stripping agent content, asphalt to diesel ratio and cold patch agent content, the influence of the component changes of cold patch asphalt liquid on the Marshall performance and water stability of the mixture was studied. It is found that the Marshall stability of LB-13 asphalt mixtures is slightly lower than that of SMA-13 asphalt mixtures, and the void ratio is 13.4%, which is conducive to diesel volatilization. Compared with SMA-13 gradation, LB-13 asphalt mixture is more suitable as the reference gradation of cold patch asphalt mixture. When the content of anti stripping agent is 0.30 % ~ 0.40 %, the Marshall stability of cold patch asphalt mixture increases gradually with the increase of anti stripping agent content, while the immersion residual stability increases first and then decreases with the increase of anti stripping agent content, and the immersion residual stability reaches the highest value (89.2 %) when the content of anti stripping agent is 0.35 %. When the ratio of asphalt to diesel is 74:24 ~ 82:16, the residual stability of cold patch asphalt mixture increases with the increase of the ratio of asphalt to diesel, and when the ratio of asphalt to diesel is more than 80:14, the Marshall stability of cold patch asphalt mixture increases significantly, which is higher than 7 kN. The Marshall stability of cold patch asphalt mixture decreases with the increase of cold patch agent when the content of cold patch agent is 1.7 % ~ 2.3 %; the immersion residual stability decreases first and then increases with the increase of cold patch agent, and reaches the highest when the content of cold patch agent is 1.7 %, which is 89.6 %. Considering the Marshall performance and water stability of cold patch asphalt mixture, when the ratio of asphalt to diesel oil is 78:20, the content of cold patch agent is 1.7 %, and the content of anti stripping agent is 0.35 %, the performance of cold patch asphalt mixture is the best.
1. Introduction

Because the asphalt binder can effectively resist the damage of driving and natural factors to the pavement, make the asphalt pavement more flat, dense, less dust and durable, the asphalt pavement is widely used in the construction of highways, urban roads and other types of roads. However, in the long-term use of asphalt pavement, ruts, potholes, cracks and other pavement diseases will gradually appear. In these pavement diseases, the pavement potholes will not only affect the pavement performance and driving comfort, but also endanger the driving safety \cite{1,2,3}. Traditionally, hot asphalt concrete is used to repair pavement potholes. This method is only suitable for roads with large engineering volume and relatively concentrated potholes \cite{4}, and can’t be constructed during rainy season and low temperature in winter \cite{5,6,7,8}. What’s more, the traffic can’t be opened immediately after construction. In view of the limitations of hot patch method in road pothole repair, scholars in the United States and the former Soviet Union began to study the cold patch asphalt mixture in the 1930s-1940s. By adding additives to realize the modification of asphalt, the cold patch asphalt mixture can be constructed at room temperature and low temperature to fill the pavement potholes \cite{9,10}. The cold patch asphalt mixture is convenient for production, construction, storage, use and repair \cite{11}. Its characteristics of high efficiency, fast, energy saving and convenience make it more and more favored by the transportation department.

China began to study cold patch asphalt mixture in the 90s of last century, but up to now, the gradation design and performance research on cold patch asphalt mixture have not formed a perfect system \cite{12}. There are still many different types of gradation design of cold patch asphalt mixture in China. Such as, the most representative LB gradation proposed in JTG F40-2004 Technical Specifications for Construction of Highway Asphalt Pavements, the AC gradation adopted by Jilin Provincial Highway Bureau, the AM gradation adopted by Taiyuan branch of Shanxi Highway Bureau, and the KN gradation adopted by Beijing Antong Corning construction materials Co., Ltd \cite{13}, LP gradation used in Tongji University \cite{14}. Because the performance of cold patch asphalt mixture is largely affected by the cold patch liquid what is prepared by mixing the base asphalt, diluent, cold patch agent and anti stripping agent evenly. Therefore, it is of great significance to study the types, mixing amount and performance of each component of cold patch liquid for the repair of pavement potholes \cite{15}. Xu Wen and others of Wuhan University of Technology have studied the initial strength, forming strength, and low temperature construction workability of cold mix asphalt mixture, and got the best content of each component of cold patch liquid, Base asphalt: Diesel: N1 (resin additive): K2 (anti stripping agent): 100:24:5:0.5, but the experiment lacks the evaluation of water stability \cite{8}. Li Feng and others from Tongji University studied the influence of different asphalt types and diluent dosage on the performance of cold patch asphalt mixture. They found that base asphalt was more suitable for preparing cold patch asphalt than SBS modified asphalt, and the Marshall stability of cold patch asphalt mixture decreased with the increase of diluent dosage \cite{16}. Li Lu et al. Studied the influence of cold patch agent content on the road performance of cold patch asphalt mixture, and found that Marshall stability and bending strain of mixture decreased with the increase of cold patch agent content, while bending strength and stiffness modulus of cold patch asphalt mixture increased with the increase of cold patch agent content \cite{17}. In view of a great variety of gradation design of cold patch asphalt mixture and the lack of systematic research on the composition design of cold patch asphalt liquid, this paper selected SMA-13 and LB-13 two skeleton gradations, used hot mix method to prepare mixture of different gradation types, and measured the volume parameter and Marshall stability to compare and select the gradation of cold patch asphalt mixtures. On this basis, the cold patch asphalt mixture was prepared. The Modified Marshall test was carried out by changing the proportion of asphalt and diesel oil, the dosage of cold patch agent and the dosage of anti stripping agent, so as to study the influence of the change of cold patch liquid on the Marshall performance and water stability of cold patch asphalt mixture.
2. Experiment

2.1. Experimental raw materials

2.1.1. Base asphalt: As a binder, base asphalt affects the later strength formation of cold patch asphalt mixture, and its performance parameters shall conform to the technical code for construction of highway asphalt pavement. AH-70 base asphalt is used in this experiment, and parameters such as penetration, softening point and ductility of asphalt are shown in Table 1.

Tab.1 Test results of AH-70 base asphalt

| Test items                      | Unit        | Test result | Technical standard | Test method |
|---------------------------------|-------------|-------------|--------------------|-------------|
| Penetration (25 °C, 5 s, 100 g) | 0.1 mm      | 60-80       | 65                 | T0604-2011  |
| Softening point                 | °C          | ≥45         | 66                 | T0606-2011  |
| Dynamic viscosity at 60 °C      | Pa•s        | ≥160        | 200                | T0620-2011  |
| Ductility                       | cm          | ≥25         | 30                 | T0605-2011  |
| Flash point                     | °C          | ≥260        | 273                | T0611-2011  |
| Density (15 °C)                 | g/cm³       | Measured records | 1.02         | T0603-2011  |
| Quality change is not greater than | %          | ≤±0.8       | -0.298             | T0609-2011  |
| Residual penetration ratio (25 °C) is not less than | %          | ≥61         | 65                 | T0604-2011  |
| Residual ductility (10 °C) is not less than | cm          | ≥6          | 15                 | T0605-2011  |

2.1.2. Aggregate: The aggregate used in the experiment is natural limestone. The apparent density is 2.62 g/cm³, the water absorption is 1.08 %, and the crushing value is 9.7 %.

2.1.3. Additive: Resin tackifier and amine anti stripping agent.

2.1.4. Diluent: The function of diluent added to asphalt is to reduce the viscosity of asphalt, so that the asphalt can maintain a certain fluidity at room temperature. The common diluents are diesel oil, kerosene, vegetable oil, gasoline, etc. in this experiment, 0 # diesel oil is selected as diluent.

2.2. Experimental scheme

In this experiment, SMA-13 gradation and LB-13 gradation in JTG F40-2004 Technical Specifications for Construction of Highway Asphalt Pavements are referred for gradation design. The mixture gradation is shown in Table 2, Table 3, and the oil stone ratio is 5.0 %. Using two gradation designs to prepare hot mix asphalt mixture, and the volume parameters and Marshall stability of SMA-13 hot mix asphalt are determined by basket method and Marshall test, the volume parameters and Marshall stability of LB-13 hot mix asphalt are determined by volume method and Marshall test. Then LB-13 gradation design is used to prepare cold patch asphalt mixture, and the best oil stone ratio is 5.0 %.
which is determined by paper trace test. In the design of cold patch asphalt liquid composition, base asphalt, diluent and cold patch agent are mixed internally, and the total content of the three components should be equal to 100%; the anti stripping agent is mixed externally, and the percentage of the content is the mass ratio of anti stripping agent and matrix asphalt. Therefore, in the experiment, the proportion of asphalt and diesel oil in cold patch asphalt liquid is controlled to 78:20, the content of cold patch agent is controlled to 2.0 %, and the content of anti stripping agent is changed to 0.30 %, 0.35 % and 0.40 % respectively to prepare cold patch asphalt mixture. Using modified Marshall test to determine the Marshall stability and residual stability of cold patch asphalt mixture.

Tab.2 Gradation of SMA-13 hot mix asphalt mixture

| Mesh size  | 0.075 | 0.15 | 0.3 | 0.6 | 1.18 | 2.36 | 4.75 | 9.5 | 13.2 |
|-----------|-------|------|-----|-----|------|------|------|-----|------|
| Upper gradation | 12.0 | 15.0 | 16.0 | 20.0 | 24.0 | 26.0 | 34.0 | 75.0 | 100.0 |
| Median gradation | 10.0 | 12.0 | 13.0 | 16.0 | 19.0 | 20.5 | 27.0 | 62.5 | 95.0 |
| Lower gradation | 8.0 | 9.0 | 10.0 | 12.0 | 14.0 | 15.0 | 20.0 | 50.0 | 90.0 |
| Synthetic gradation | 10.0 | 12.2 | 13.0 | 14.9 | 18.1 | 21.1 | 32.0 | 77.1 | 97.8 |

Tab.3 Gradation of LB-13 hot mix asphalt mixture

| Mesh size  | 0.075 | 0.15 | 0.3 | 0.6 | 1.18 | 2.36 | 4.75 | 9.5 | 13.2 |
|-----------|-------|------|-----|-----|------|------|------|-----|------|
| Upper gradation | 5.0 | 8.0 | 12.0 | 15.0 | 20.0 | 40.0 | 60.0 | 95.0 | 100.0 |
| Median gradation | 2.5 | 4.0 | 6.0 | 7.5 | 12.5 | 25.0 | 45.0 | 77.5 | 95.0 |
| Lower gradation | 0.0 | 0.0 | 0.0 | 0.0 | 5.0 | 10.0 | 30.0 | 60.0 | 90.0 |
| Synthetic gradation | 3.5 | 7.2 | 8.5 | 11.7 | 17.1 | 22.3 | 39.4 | 84.3 | 98.3 |

On this basis, the content of anti stripping agent is controlled unchanged, the content of cold patch agent is 2.0 %, and the proportion of asphalt and diesel oil is changed to 74:24, 76:22, 78:20, 80:18 and 82:16 respectively to prepare cold patch asphalt mixture, using modified Marshall test to determine the Marshall stability and residual stability of cold patch asphalt mixture. On this basis, controlling the content of anti stripping agent and the proportion of asphalt and diesel oil to prepare cold patch asphalt mixture by changing the content of cold patch agent to 1.7 %, 2.0 % and 2.3 % respectively, testing the Marshall stability and residual stability of cold patch asphalt mixture by modified Marshall test.

2.3. Experimental method

2.3.1. Preparation of cold patch asphalt mixture: Heating the matrix asphalt to 130 °C ± 10 °C, adding proper amount of 0 # diesel oil, cold patch agent and anti stripping agent in the matrix asphalt and mixing evenly to prepare the cold patch asphalt liquid. Cooling down until the heating temperature of the cold rehydration fluid is 90 °C ± 10 °C, and then heating the mixing pot and the aggregate to 75 °C ±5 °C. The mixture is placed in the mixing pot and mixed for 5 s ~ 10 s, and the cold patch asphalt liquid is uniformly mixed with the aggregate for 35 s ~ 40 s to make the cold patch asphalt mixture.

2.3.2. Modified Marshall test: Referring to Li Feng's modified Marshall test, a proper amount of cold patch asphalt mixture was put into the Marshall test mold at room temperature, and the two sides were pressed for 25 times. Putting it together with the test mold in an oven at 110 °C for 24 hours in a side vertical manner, taking it out and then compacting it on both sides for 25 times to make Marshall test piece. The height of the test piece shall meet 63.5 mm ± 1.3 mm. The test piece is demoulded at room temperature for 24 hours, and the demoulded test piece is placed in a constant temperature water tank at 25 °C for 30 minutes for Marshall test. The demoulded test piece is placed in a constant
temperature water tank at 25 °C for 48 hours for Marshall test to calculate the immersion residual stability [18].

3. Results and analysis

3.1. Gradation design research

In the experiment, SMA-13 and LB-13 hot mix asphalt mixtures were prepared. Through the study of the volume parameters and Marshall stability of SMA-13 and LB-13 skeleton asphalt mixtures, the gradation what is suitable for cold patch asphalt mixtures could be effectively evaluated. The volume parameters and Marshall stability results of SMA and LB gradation asphalt mixtures are shown in Table 4.

Table 4 shows that the Marshall stability of SMA-13 asphalt mixture and LB-13 asphalt mixture is 8.92 kN and 7.37 kN respectively, and there is little difference in the Marshall stability of the two kinds of asphalt mixture. This shows that the interlock of aggregate in the skeleton asphalt mixture structure can improve very high strength, so it is suitable to choose skeleton structure for cold patch asphalt mixture. The VV, VMA and VFA of SMA-13 asphalt mixture are 3.5 %, 11.4 % and 76.2 % respectively. The VV, VMA and VFA of LB-13 asphalt mixture are 13.4 %, 23.7 % and 43.4 % respectively. The void ratio and voids in mineral aggregate of LB-13 asphalt mixture are significantly higher than that of SMA-13 asphalt mixture. If SMA structure is used to prepare cold patch asphalt mixture, the strength of mixture will not be formed due to the difficulty of diesel volatilization, the LB skeleton void structure is selected, because it is more conducive to diesel volatilization and it’s in favor of the strength of cold patch asphalt mixture.

| Tab.4 Volume parameters and Marshall stability of two different grades of hot mix asphalt mixtures |
|-----------------------------------------------|
| Marshall stability/kN | Theoretical maximum relative density | Gross volume relative density | VV/% | Asphalt volume percentage/% | VMA/% | VFA/% |
|-----------------------|--------------------------------------|-------------------------------|------|----------------------------|-------|-------|
| SMA-13                | 8.92                                 | 2.533                         | 2.443| 3.5                        | 11.4  | 76.2  |
| LB-13                 | 7.37                                 | 2.563                         | 2.219| 13.4                       | 23.7  | 43.4  |

3.2. Effect of anti stripping agent dosage on properties

Because the content of anti stripping agent has a great influence on Marshall performance and water stability of cold patch asphalt mixture, this paper studied the content of anti stripping agent first, so as to ensure that the later study of cold patch asphalt mixture had a certain forming strength for performance study. Experiment controlled the proportion of asphalt and diesel oil was 78:20, the content of cold filler was 2.0 %, and studied the influence of anti stripping agent content on Marshall performance and water stability of cold patch asphalt mixture. The measured Marshall stability and immersion residual stability are shown in Table 5, Figure 1 and Figure 2.

| Tab.5 Modified Marshall test results of cold mix asphalt mixture with different anti stripping agents |
|-----------------------------------------------|
| Dosage of anti stripping agent/% | Marshall stability/kN | Stability after 48h immersion /kN | Immersion residual stability/% |
|---------------------------------------|-----------------------|-----------------------------------|-----------------------------|
| 0.30                                  | 5.86                  | 4.77                              | 81.3                        |
| 0.35                                  | 6.10                  | 5.44                              | 89.2                        |
| 0.40                                  | 6.32                  | 5.57                              | 88.1                        |
According to the analysis of Table 5, Figure 1 and Figure 2, when the content of anti stripping agent increases from 0.30% to 0.35 %, the Marshall stability and water stability of cold patch mixture increase significantly, the Marshall stability of mixture increases from 5.86 kN to 6.10 kN, and the immersion residual stability increases from 81.3 % to 89.2 %. This is because the physical adsorption can be formed on the surface of asphalt by adding anti stripping agent, which can improve the adhesion between asphalt and aggregate under the joint action of physical adsorption and chemical adsorption. With the increase of anti stripping agent, the physical adsorption will also increase, so that the strength and water damage resistance of cold patch asphalt mixture will be enhanced. However, when the content of anti stripping agent continues to increase to 0.40 %, the residual stability of cold patch asphalt mixture decreases to 88.1 %. The reason is that the amine anti stripping agent in cold patch asphalt mixture decomposes in the process of curing and water bath. The decrease of anti stripping agent reduces the physical adsorption between asphalt and aggregate, and the water stability of asphalt mixture also decreases. Therefore, considering Marshall property and water stability, 0.35 % is the best dosage of antistripping agent.

### 3.3. Influence of asphalt to diesel ratio change on performance

The experiment controlled anti-stripping agent content was 0.35 %, cold supplement content was 2.0 %, studied the influence of the asphalt and diesel ratio change on the Marshall performance and water stability of cold patch asphalt mixture, Marshall stability and immersion residual stability measured results are shown in Table 6, Figure 3, Figure 4.

| Base asphalt: Diesel | Marshall stability/kN | Stability after 48h immersion /kN | Immersion residual stability/% |
|----------------------|------------------------|-------------------------------|-------------------------------|
| 74:24                | 6.71                   | 4.98                          | 74.2                          |
| 76:22                | 6.48                   | 4.93                          | 76.1                          |
| 78:20                | 6.86                   | 5.38                          | 78.4                          |
| 80:18                | 6.38                   | 5.15                          | 80.7                          |
| 82:16                | 7.52                   | 6.63                          | 88.2                          |
It can be observed from Table 6, Figure 3 and Figure 4 that with the increase of the proportion of asphalt and diesel oil in the cold patch asphalt liquid, the immersion residual stability also increases, and when the proportion of asphalt and diesel oil is 82:16, the immersion residual stability of the cold patch asphalt mixture is the largest, reaching 88.2%. The performance of the asphalt mixture is well. This is because asphalt content increases with the proportion of asphalt and diesel oil, which makes the viscosity of cold patch liquid increase. The thickness of asphalt film between aggregates increases when the mixture is formed. When the water enters the gap of cold patch asphalt mixture, the thicker asphalt film helps to resist the interface damage between asphalt and aggregates. When the ratio of asphalt to diesel is 74:24 ~ 80:18, the Marshall stability of cold patch asphalt mixture has little difference. This is because the asphalt cohesion in LB cold patch asphalt mixture has little influence on the initial strength of the mixture, and the strength of the mixture is mainly provided by the internal friction resistance between aggregates. When the ratio of asphalt to diesel is greater than 80:18, the cohesion provided by asphalt has reached the degree of influence on the strength of cold patch asphalt mixture, so the Marshall stability of cold patch asphalt mixture increased significantly, reaching 7.52 kN. However, when the ratio of asphalt to diesel reaches 82:16, the workability and storage performance of cold patch asphalt mixture is poor. Therefore, the ratio of asphalt to diesel should be 78:20 for further study.

3.4. Influence of the amount of cold patch agent on properties
Fixing the content of the anti stripping agent is 0.35 %, and the proportion of asphalt and diesel oil is 78:20. The influence of the content of the cold patch agent on the Marshall performance and water stability of the cold patch asphalt mixture is studied. The measured Marshall stability and immersion residual stability are shown in Table 7, Figure 5 and Figure 6.

| Dosage of cold patch agent /% | Marshall stability/kN | Stability after 48h immersion /kN | Immersion residual stability/% |
|------------------------------|------------------------|-----------------------------------|------------------------------|
| 1.7                          | 7.12                   | 6.38                              | 89.6                         |
| 2.0                          | 6.86                   | 5.38                              | 78.4                         |
| 2.3                          | 6.69                   | 5.76                              | 86.1                         |
It can be observed from Table 7, Figure 5 and Figure 6 that when the content of cold patch agent is 1.7 % ~ 2.3 %, the Marshall stability of cold patch asphalt mixture decreases gradually with the increase of the content of cold patch agent, from 7.12 kN to 6.69 kN. The decrease of Marshall stability is because the increase of cold patch agent leads to the decrease of asphalt content. One of the mechanisms for forming the strength of cold patch asphalt mixture is the adhesion between asphalt and aggregate. The decrease of asphalt makes the adhesion between asphalt and aggregate weaken, and the strength of mixture decrease. When the content of cold patch agent is 1.7 % ~ 2.0 %, the residual stability of cold patch asphalt mixture decreases from 89.6 % to 78.4 %, and when the content of cold patch agent is 2.0 % ~ 2.3 %, the residual stability of cold patch asphalt mixture increases from 78.4 % to 86.1 %. With the increase of cold patch agent, the viscous effect of cold patch agent is weaker than that of asphalt, and the decrease of asphalt makes the water stability of cold patch asphalt mixture decrease first. When the content of cold patch agent is appropriate, the viscous effect of cold patch agent is enough to make up for the decrease of water stability caused by the decrease of asphalt content, and the residual stability of mixture increases. The Marshall stability and immersion residual stability of cold patch asphalt mixture with different dosage of cold patch agent were comprehensively compared. In this paper, 1.7 % of cold patch agent was selected as the optimal dosage.
4. Conclusion

1) The Marshall stability of LB-13 hot mix asphalt mixture is slightly lower than that of SMA-13 hot mix asphalt mixture, and the void ratio of LB-13 asphalt mixture is 13.42 %, the voids in mineral aggregate is 23.73 %; the void ratio of SMA-13 asphalt mixture is 3.54 %, the voids in mineral aggregate is 14.89 %. The void ratio and voids in mineral aggregate of LB-13 asphalt mixture are higher than those of SMA-13 asphalt mixture. The formation mechanism of strength of cold patch asphalt mixture is integrated, and this kind of large void structure is more conducive to the volatilization of diesel oil, so that the later strength of the mixture can be increased rapidly. Therefore, LB-13 gradation is selected as the reference gradation of cold patch asphalt mixture.

2) When the content of anti stripping agent is 0.30 % ~ 0.40 %, the Marshall stability of cold patch asphalt mixture increases gradually with the increase of the content, and the maximum is 6.32 kN. The results show that the immersion residual stability of cold patch asphalt mixture increases first and then decreases. When the content of antistripping agent is 0.35 %, the maximum immersion residual stability of cold patch asphalt mixture is 89.2 %. Considering the Marshall performance and water stability, the amount of anti-stripping agent should be controlled at 0.35 %.

3) When the ratio of asphalt to diesel oil is 74:24 ~ 82:16, with the increase of the ratio of asphalt to diesel oil, the immersion residual stability of cold patch asphalt mixture increases gradually, and the maximum is 88.2 %. When the ratio of asphalt to diesel is more than 80:14, the Marshall stability of cold patch asphalt mixture increases with the increase of the ratio of asphalt to diesel, up to 7.52 kN, but the construction performance of the mixture decreases. In order to take into account the strength and construction workability, the ratio of asphalt to diesel should be 78:20.

4) When the content of cold patch agent is 1.7 % ~ 2.3 %, with the increase of the content, the Marshall stability of cold patch asphalt mixture decreases gradually, and the immersion residual stability decreases first and then increases. When the content of cold patch agent is 1.7 %, the Marshall stability and immersion Marshall stability of cold patch asphalt mixture reach the maximum, which are 7.12 kN and 89.6 %, respectively.

5) In this paper, the influence of different gradations and components of cold patch liquid on the performance of cold patch asphalt mixture is studied by control variable method. By using LB-13 type grading design, and controlling the proportion of asphalt and diesel oil in the cold patch solution is 78:20, the content of cold patch agent is 1.7 %, the content of anti stripping agent is 0.35 %. The Marshall performance and water stability of the cold patch asphalt mixture are all at a better level, and its Marshall stability can reach 7.12 kN, and the residual stability of immersion can reach 89.6 %

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