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Study on preparation of light oil regenerant and performance of cold recycled mixture

Xiaofeng Huang[1], Cheng Xie[1], Jiangcai Chen[1], Junhui Luo[1], Di Wei[1]

[1]Guangxi Beitou Transportation Maintenance Technology Group Co., Ltd. 530000, Nanning, China.
e-mail: xiaophenix@163.com, yhjtxiec@bgigc.com, jebblues@163.com, jhluo85@hotmail.com, btyhkj_vivid@163.com

ABSTRACT

In order to make full use of aged asphalt, a light oil regenerant for cold mixing was prepared in this paper, and the ratio of regenerant and regeneration effect was studied through the performance test of recycled asphalt. The ratio of regenerant was determined by 60 °C kinematic viscosity, mass loss before and after aging, and asphalt three indicators. The thermogravimetric analysis determined the four-component ratio of recycled asphalt, and the mechanical properties of the recycled asphalt mixture were determined by the 15 °C splitting and 20 °C compression tests. Finally, the road performance of the recycled asphalt mixture was analyzed by rutting, low-temperature bending, and dry-wet splitting tests. When the mass ratio of light base oil: plasticizer: stable equilibrium agent: penetrant: the anti-aging agent is 80:20:25:8:5, it has a good regeneration effect. After adding 8% regenerant, the regenerated asphalt is compared with the recycled asphalt. The content of saturates and aromatics increases, and the content of resins and asphaltenes decreases. The four-component content of recycled asphalt is close to that of new asphalt. The mechanical properties test shows that the optimum content of the regenerant is 0.9%. With increased RAP content, the water stability and low-temperature crack resistance are also improved, and the high-temperature stability is reduced. However, it still meets the requirements of the regeneration specification.

Keywords: Road engineering; Reclaimed mixture; Light oil regenerant; Road performance.

1. INTRODUCTION

With the high use time, many roads have different degrees of diseases [1]. Renovation, reconstruction, and maintenance of these highways are urgent problems for road workers [2]. The asphalt pavement recycling technology is undoubtedly the best way to solve these diseases because the asphalt pavement recycling technology can not only realize the reuse of the old asphalt mixture of the diseased pavement but also save resources and protect the environment [3]. On the one hand, using recycling technology to repair the diseased pavement can reduce the environmental pollution caused by the old asphalt mixture [3]; on the other hand, it can also turn waste into treasure and save resources. Whether the heating is needed in the regeneration process is mainly divided into hot regeneration technology and cold regeneration technology. Because cold recycling technology does not need to heat aggregate, it can save more energy, and the utilization rate of old asphalt mixture is also high, so it is widely used [4].

In the process of secondary utilization of RAP materials, the traditional cold recycling technology of asphalt pavement usually treats RAP materials as 'black aggregate,' that is, ignores the aging asphalt coated on the surface of RAP materials and then mixes them with new asphalt materials and new aggregates in a certain proportion [5]. Finally, it is paved on the pavement to achieve recycling [6, 7]. In this way, many asphalt resources are wasted. Emulsified asphalt and cement are mainly used as bonding materials in the regeneration process [8]. The construction period of recycled pavement is long, and the early strength of pavement is low. The strength development is slow, and the recycled mixture's water stability and fatigue performance could be better. The recycled mixture prepared by the traditional cold regeneration method is used more in the pavement structure's base layer and less in the surface layer [4]. Therefore, the cold recycled pavement uses the old asphalt mixture as the 'black aggregate' during regeneration [9]. The cold recycling technology needs to be improved mainly by making full use of the aged asphalt, and the performance of the aged asphalt is restored and re-applied to the recycled pavement so that the early strength of the recycled asphalt mixture can be improved by using the aged asphalt [10, 11].

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According to the principle of similar miscibility between organic substances, light oil can dissolve the associated asphalt, reduce the length and mutual attraction of macromolecular chains in aging asphalt, and thus obtain cohesion in the process of mixture compaction [12]. At the same time, under the dilution and dissolution of light oil, the regenerant can be more easily combined with the aged asphalt to improve the properties of the aged asphalt. Therefore, in the cold recycled asphalt mixture, the light oil regenerant has great advantages over other regenerants, because it improves the performance of aged asphalt and exerts the cohesion of aged asphalt [13].

Based on this, this paper uses a light oil regenerant to dilute and dissolve aged asphalt [14], preparing a cold regenerant and its preparation and application method. The regenerant comprises light base oil, stabilizer, plasticizer, penetrant, and anti-aging agent. Given this, the best content of adding regenerant is determined based on the strength of the cold recycled asphalt mixture. The rotary compaction method forms the emulsified asphalt cold recycled mixture, and the mix ratio is designed. The effect of regenerant content on the mixture's strength characteristics and durability was analyzed by the 15 °C splitting test and compression test. Then, according to the best content of regenerant, the regenerant was added to the old asphalt mixture for a road performance test, and the effect of light oil regenerant on the road performance of cold recycled asphalt mixture was studied to improve the service life of cold recycled asphalt pavement by using light oil regenerant. The regenerant can restore the component balance of aged asphalt, realize the recycling of RAP, turn waste into treasure, and promote the application of cold recycling technology.

2. MATERIALS AND METHODS

2.1. Raw materials

2.1.1. Asphalt mixture

The old asphalt mixture is taken from a main road in Guilin, Guangxi. The road has been used for six years, and the road cracks and ruts are serious. The moisture content of the old asphalt mixture measured by the drying method is 0.7%. Since the test regenerant is mainly based on the content of the aged asphalt, the asphalt-aggregate ratio of the old asphalt mixture was measured to be 4.2% by the Abson asphalt recovery method. Therefore, it is estimated that the content of regenerant is added at an interval of 0.3% and with 0.9% of the mass of the old material. The old material gradation is obtained through screening and weighing the old material, as shown in Table 1.

The old asphalt mixture is not heated in the process of utilization. If the unextracted aggregate size is too large, the aggregate size after extraction is calculated in the mix design. The mix design of cold recycled asphalt mixture differs from that of the ordinary mixture. The specification determines the gradation value range. In this paper, medium-grained gradation is used. When the gradation of milling material does not meet the requirements of engineering gradation, limestone gravel aggregate is added. According to the raw material screening results and engineering design grading range, the grading curve is determined after adjustment and optimization, as shown in Figure 1. The test uses slow-cracking and slow-setting cationic emulsified asphalt, and the performance of emulsified asphalt meets the specification requirements. Ordinary Portland cement with strength grade of 32.5 was selected as external admixture, and its dosage was 1.5%. The technical indexes of new aggregate, cement, and mineral powder meet the requirements.

2.1.2. Regenerant

The regenerant is a mixture of light base oil, stabilizer, plasticizer, penetrant, and anti-aging agent. Among them, the light oil is a mixture of reduced fourth-line furfural extract oil and rubber oil, the plasticizer is epoxidized soybean oil, the stabilizer is heavy oil with high content of colloid, the penetrant is heavy oil with high aromatic content, and the anti-aging agent is organically modified nan montmorillonite. Among them, the light base oil in the regenerant is rich in aromatic hydrocarbons and has a solid ability to dissolve asphaltenes; the plasticizer can be inserted between the polymer molecular chains to weaken the interaction between the asphalt molecular chains and increase the mobility of the asphalt molecular chains, thereby improving the low-temperature ductility

Table 1: Old asphalt mixture gradation.

CUMULATIVE PASSING PERCENTAGE (%)	19	16	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.05	0.075
RAP	99.6	97.1	91.2	73.8	33.8	5.3	2.0	0.8	0.3	0.1	0
Extracted aggregate	99.8	97.3	92.3	77.1	53.5	26.4	19.2	13.5	9.1	5.8	2.7

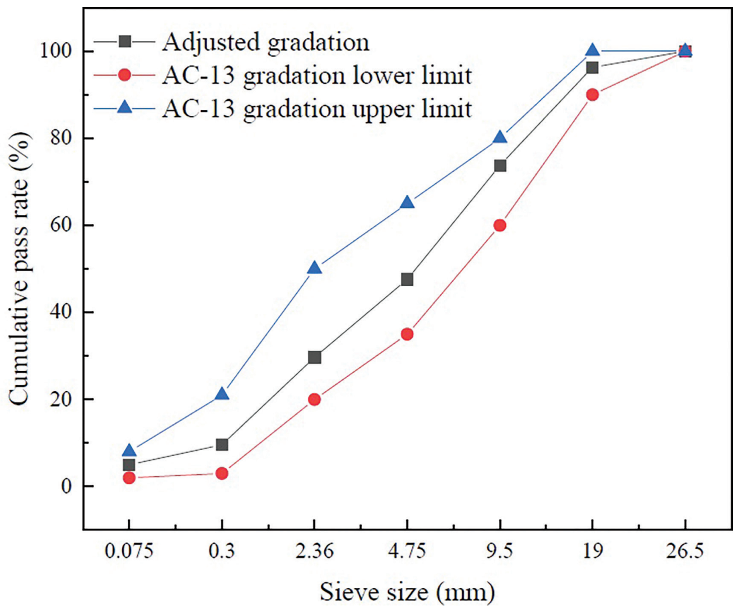

Figure 1: Composite gradation curve of emulsified asphalt cold recycled mixture.

of the aged asphalt. The stabilizer ensures the balance of the reclaimed asphalt colloid system; the penetrating agent increases the penetration effect of the regenerant and makes the regenerant fuse with the aged asphalt on the surface of the stone during the mixing process, which can improve the regeneration performance of the asphalt regenerant and be used for the regeneration of waste asphalt. The raw materials of asphalt regenerant prepared in this paper are environmentally friendly and will not pollute the environment.

The preparation method of the regenerant is as follows: the light base oil is heated to 60 °C, and the stabilizer, penetrant, and plasticizer are added to stir evenly. The stirring rate is 400r/min, the stirring temperature is 60 °C, and the stirring time is 20min. After the temperature is raised to 120 °C, the anti-aging agent is added and shear stirring evenly, and the asphalt regenerant is obtained by natural cooling. The shear rate is 2000r/min, shear temperature is 120 °C and the shear time is 20min.

2.2. Test method

2.2.1. Splitting test

The indirect tensile strength of the cold recycled asphalt mixture was evaluated by splitting test. The standard Marshall specimens of φ101.6 mm × h 63.5 mm were prepared according to the test procedure of asphalt and asphalt mixture for highway engineering T 0702-2011. The specimens were placed in a 15 °C environment box for 6 hours, and then the splitting test was carried out by a universal testing machine. The test temperature was 15 °C, and the loading rate was 50 $mm \cdot min^{-1}$.

2.2.2. Uniaxial compression test

The compressive strength of the cold recycled asphalt mixture was evaluated by uniaxial compression test. According to the uniaxial compression test method of asphalt mixture in JTG E20-2011 'Highway Engineering Asphalt and Asphalt Mixture Test Procedures', the specimens were placed in a 20 °C environment box for 6 h and then subjected to uniaxial compression test by a universal testing machine. The test temperature was 20 °C, and the loading rate was 2 $mm \cdot min^{-1}$.

2.2.3. Rutting test

The rutting test was used to evaluate the high-temperature stability of the cold recycled asphalt mixture. According to the rolling wheel method of 'Highway Engineering Asphalt and Asphalt Mixture Test Regulations' T0703-2011, a standard rut plate specimen of 300 mm × 300 mm × 50 mm was made. In the early stage of the test, the specimen was placed in a 20 °C environment box and kept at a constant temperature for 6 hours before the rut test. During the test, the pressure of the grinding wheel on the specimen was 0.7MPa, and the test temperature was 60 °C.

2.2.4. Low-temperature trabecular bending test

The low-temperature trabecular bending test was used to evaluate the low-temperature crack resistance of the cold recycled asphalt mixture. According to JTG E20 T0715-2011, the prepared rut plate was cut into a 250 mm × 35 mm × 30 mm trabecular specimen and placed in a thermostatic freezing solution at −10 °C for 4 h. Then the bending test was carried out by CMT5105 microcomputer-controlled electronic universal testing machine. The test temperature was –10 °C, and the loading rate was 2 mm·min^{-1}.

2.2.5. Dry-wet splitting test

A dry-wet splitting test evaluated the water stability of the cold recycled asphalt mixture. Firstly, the standard Marshall specimens were prepared and divided into two groups. One group was subjected to a splitting test after 6 hours of heat preservation in a constant temperature water bath at 15 °C, and the dry splitting strength was measured. The other group was first kept in water at 25 °C for 23 h and then in water at 15 °C for 1 h. The wet splitting strength was measured. The test temperature was 15 °C, and the loading rate was 50 mm·min^{-1}.

3. REGENERANT PERFORMANCE AND RATIO

3.1. Regenerant performance

The test scheme of the regenerant mass ratio design is shown in Table 2. Among them, A is light base oil, B is a plasticizer, C is a stabilizer, D is a penetrant, and E is an anti-aging agent.

It can be seen from Table 2 that with the decrease in plasticizer ratio and the increase of base oil and stabilizer ratio, the viscosity of the regenerant shows a decreasing trend. The kinematic viscosity of No.1 and No.2 at 60 °C is higher than 200 cSt, which does not meet the technical standard of 'cold mix asphalt regeneration agent' (CJ/T529-2018), and the other three meet. By analyzing the viscosity ratio and mass loss results before and after the rotary film oven, it was found that the viscosity ratio and mass loss of the five regenerant ratios were low, which met the requirements of the specification, and the No.3 regenerant had the best performance in anti-aging performance.

Penetration, ductility, and softening point are three characteristic indexes of asphalt materials that characterize the performance of asphalt from different angles. Therefore, the regeneration effect of the cold recycling agent can be evaluated by measuring the improvement of the three indicators of aging asphalt by the cold recycling agent. Different types of cold recycling agents were thoroughly mixed with the aging asphalt prepared in the laboratory, in which the content of the recycling agent was 8%, then regenerated in the room temperature environment for two days. The three indexes of aging asphalt before and after regeneration were measured by a penetration test, softening point test, and ductility test. The cold recycling agent type with a better regeneration effect was analyzed. The test results are shown in Table 3. Among them, 0 represents laboratory-aged asphalt without regenerant, and 6 is AH-70 matrix asphalt.

It can be seen from the test results in Table 3 that the five rejuvenators have a good recovery effect on the three primary indicators of aged asphalt. Because the light base oil has better dissolution and softening ability to the aged asphalt, and the plasticizer ratio can increase the viscosity of the regenerant and reduce the penetration of the asphalt, the penetration of the five recycled asphalts shows an increasing trend, and the softening point shows a decreasing trend. Since the plasticizer has a good effect on improving the low-temperature ductility of recycled asphalt, the ductility generally shows a downward trend.

The minimum penetration requirement of AH-70 matrix asphalt is 60, so No.1 and No.2 regenerant do not meet the requirements. The ductility of recycled asphalt No.4 and No.5 is less than 100 mm. When the content of regenerant is 8%, the softening point index of No.3 recycled asphalt is restored to the level of

Table 2: Performance results of regenerant.

REGENERANT NUMBER	A:B:C:D:E	60 °C KINEMATIC VISCOSITY (cSt)	ROTATING FILM OVEN BEFORE AND AFTER	
			RATIO OF VISCOSITY	MASS LOSS (%)
1	70:30:20:6:5	212	2.6	0.62
2	75:25:20:6:5	201	2.3	0.53
3	80:20:25:8:5	175	1.9	0.47
4	85:15:25:8:5	159	2.1	0.51
5	90:10:30:10:5	135	1.9	0.48

Table 3: Performance of recycled asphalt.

REGENERANT NUMBER	25 °C PENETRATION (0.1 mm)	15 °C DUCTILITY (cm)	SOFTENING POINT (°C)
0	48.8	59.7	63.2
1	53.7	105.7	52.5
2	59.5	102.6	52.1
3	66.6	100.5	50.3
4	69.1	88.3	51.5
5	70.9	82.4	48.8
6	75.3	>100	47.9

Table 4: Regenerant and asphalt four component test results.

MATERIALS	SATURATES	AROMATIC	RESIN	ASPHALTENE
Regenerant	24.36	54.38	19.01	2.25
New asphalt	19.85	41.89	24.63	13.63
Old asphalt	15.86	33.24	31.10	19.80
Recycled asphalt	18.45	37.85	25.00	15.7

AH-70 matrix asphalt. In summary, using the No.3 ratio of regenerant (8% content) can meet its performance requirements and recycled asphalt performance indicators and has good anti-aging performance.

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It can be seen from Table 4 that the prepared regenerant has a high aromatic content and a low asphaltene content, which can reasonably adjust the four-component balance of aged asphalt. Compared with recycled asphalt, the content of saturates and aromatics increased, and the content of resins and asphaltenes decreased. The four-component content of recycled asphalt is close to that of new asphalt. From the analysis of the four-component test results of asphalt, this rejuvenator can adjust the balance of components in asphalt so that the missing components in the aged asphalt can be supplemented to match the new asphalt.

3.3. Mechanical properties of recycled mixture

The optimum moisture content of recycled asphalt mixture is 5.4% (obtained from Geotechnical Compaction test), the optimum emulsified asphalt content is 4.2% (obtained from Marshall test), the recycling agent No.3 is selected, and the recycling agent content is 0.3%, 0.6%, 0.9%, 1.2% and 1.5%. Five groups of recycled asphalt mixture specimens were formed, and the specimens' 15 °C splitting strength and 20 °C compressive strength were tested.

It can be seen from Figure 2 that after adding the regenerant, the 15 °C splitting strength of the emulsified asphalt cold recycled mixture increases first and then de-creases. Compared with the splitting strength of the cold recycled asphalt mixture without the regenerant (0.44MPa), when the regenerant content is 0.9%, the dry splitting strength of the cold recycled mixture reaches the extreme value 0.58MPa, which is increased by 31.8%. This shows that an appropriate amount of regenerant can improve the cohesion of the cold recycled mixture, thereby improving its tensile strength. With the increase of the content of regenerant, the compressive strength of the mixture also increases first. Then it decreases, indicating that the content of regenerant also improves the compressive strength, but the improvement effect is not ap-parent. When the content of regenerant is 0.9%, the compressive strength reaches the maximum (2.08MPa), which is increased by 18.9%. However, when the amount exceeds 0.9%, the compressive strength is lower than that of the aged asphalt mixture. When the content

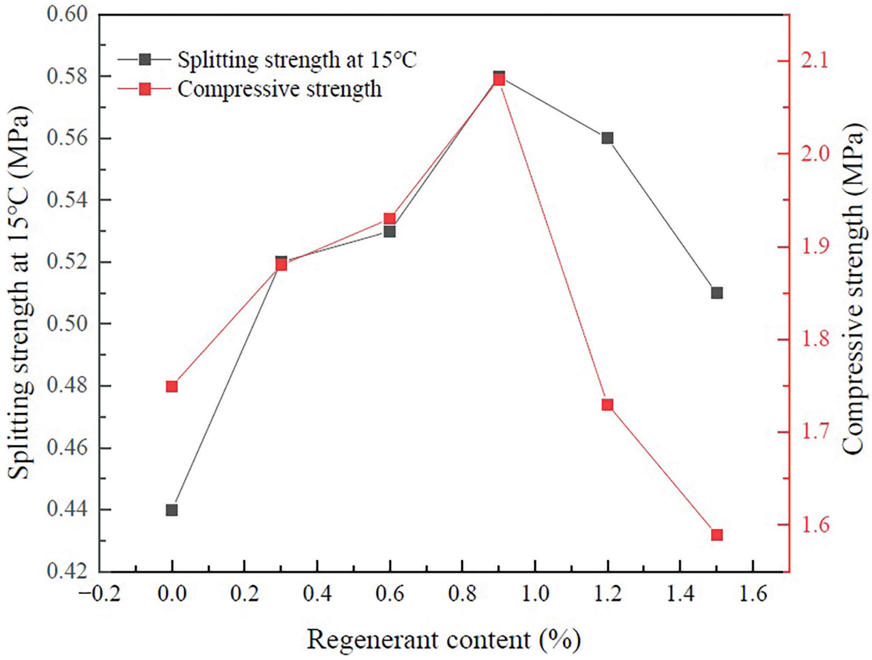

Figure 2: Mechanical properties of recycled asphalt mixture with different content of regenerant.

of light oil regenerant exceeds 0.9%, the strong performance of the recycled mixture decreases. This is because when the content of the regenerant is less than 0.9%, the aged asphalt on the surface of the old asphalt mixture is diluted and dissolved, and the performance of the aged asphalt is improved. However, the improvement effect is not optimal due to the small content of the regenerant. When the content of the regenerant is more than 0.9%, the light base oil and penetrant in the regenerant dilute the aged asphalt seriously, which reduces the cohesion and mechanical properties. Based on the above test results, the optimum dosage of regenerant was determined to be 0.9%.

4. PAVEMENT PERFORMANCE OF COLD RECYCLED ASPHALT MIXTURE

4.1. High-temperature stability

The rutting test simulates the high-temperature rutting resistance of a road under average traffic load in the laboratory, which is usually used to evaluate the high-temperature dynamic stability of the asphalt mixture. In this paper, the rutting test of cold recycled asphalt mixture with 70%, 80%, 90%, and 100% RAP content is carried out to explore the influence of RAP content on the high-temperature perfor-mance of cold recycled asphalt mixture.

It can be seen from Figure 3 that the dynamic stability decreases gradually with the increase of RAP content. When the content of RAP is 70%, the maximum dynamic stability is 5350 times/mm. In increasing the content of RAP, the dynamic stability decreases continuously. When the RAP content is 100%, the minimum dynamic stability is only 2250 times/mm, and the dynamic stability decreases significantly. When the old material is small, only emulsified asphalt and cement in the cold recycled asphalt mixture make it rigid, so the dynamic stability is high. When the content of old materials increases, the content of aged asphalt increases. Under 60 °C, the light oil regenerant softens the recycled asphalt and the demulsified aged asphalt. In the process of the rutting test, the softening effect of repeated rolling of the load wheel is more prominent, so the dynamic stability decreases obviously. However, regardless of the amount of RAP, the dynamic stability of cold recycled asphalt mixture can meet the requirements of road performance.

4.2. Low-temperature crack resistance

Adding a light oil regeneration agent to the mixture can significantly improve some of its performance, but the typical environment is rigid because of its small amount of asphalt. In the low-temperature condition of the specimen, performance is poor. Therefore, the beam bending test of cold recycled asphalt mixture with different RAP content is carried out. The relationship between RAP content and failure stress and strain can be obtained through the final test results, as shown in Figure 4.

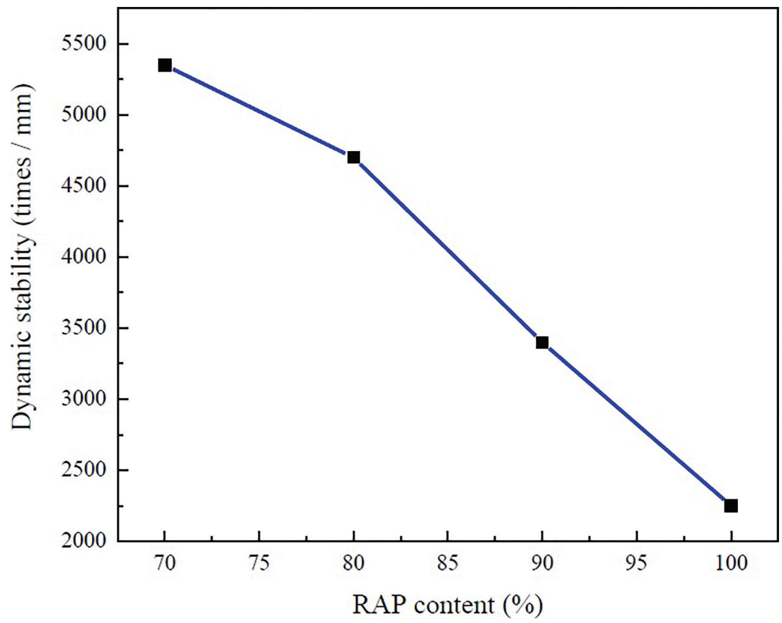

Figure 3: Dynamic stability under different RAP content.

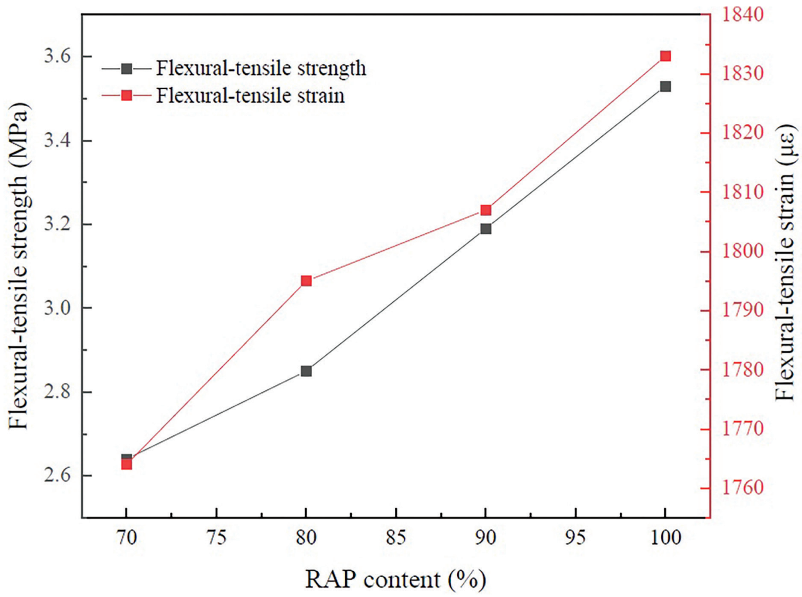

Figure 4: Low temperature trabecular bending test results of different RAP content.

It is generally believed that asphalt mixture with high RAP content has high brittleness and low toughness, and low-temperature performance will be significantly reduced. It can be concluded from Figure 4 that in the process of increasing the number of old materials, the flexural strength of the mixture gradually increases while the flexural strain gradually decreases. This is because of the increase in the amount of RAP and the increase in the content of aged asphalt. The light base oil in the rejuvenator dissolves and softens the asphaltene. The plasticizer weakens the interaction between the molecular chains of the asphalt, which can further promote the rejuvenator in the aged asphalt. The degree of diffusion increases so that the modulus of the aged asphalt is further reduced, and the flexibility of the cold recycled mixture is increased, thereby increasing the low-temperature ductility of the aged asphalt and improving the low-temperature crack resistance.

4.3. Water stability

The water stability determines the corrosion resistance of the mixture in harsh weather such as rain and snow. Therefore, this paper studies the effect of RAP content on the water stability of recycled asphalt mixture by splitting strength and splitting strength ratio. The test results are shown in Figure 5.

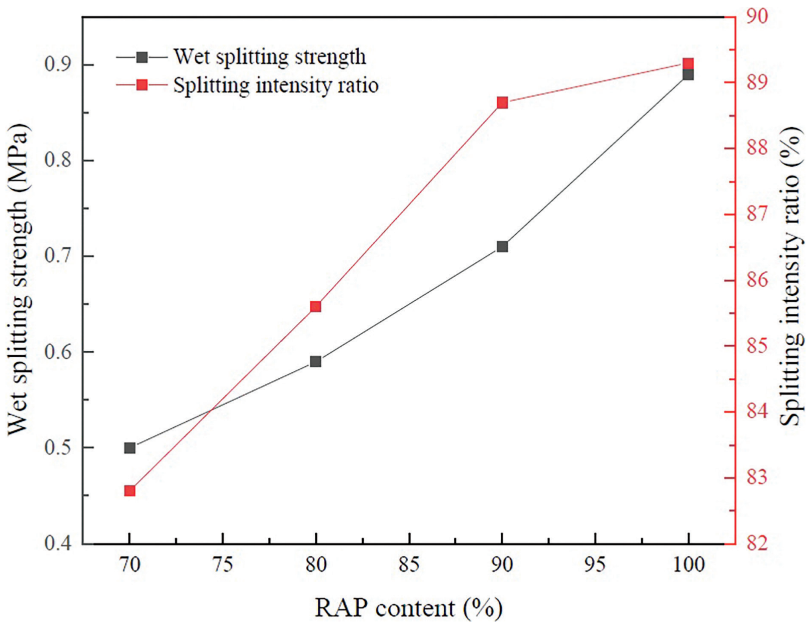

Figure 5: Water stability test results of different RAP content.

It can be seen from Figure 5 that the wet splitting strength of the mixture increases with the increase of the number of old materials and has a linear relationship with the RAP content. The splitting strength ratio also increases with the increase of RAP content. There are two main reasons for this. Firstly, the aged asphalt in the inner layer of the recycled mixture forms a robust interface with high viscosity on the mineral aggregate's surface, making it difficult for water to penetrate. Secondly, when the content of old material is small, the content of aged asphalt is relatively low, and the contribution of recycled asphalt to the cohesion of recycled asphalt mixture is limited. With the increase of the content of old material, the content of aged asphalt is also relatively improved. After the improvement of the light oil regeneration agent, the number of recycled asphalts increases, so the cohesion is improved. Because the light oil regeneration agent belongs to the oil material, the hydrophobicity is obvious, and the residual splitting strength ratio increases. According to the 'Highway Asphalt Pavement Regeneration Technical Specification' (JTG F41-2008) standard, the splitting strength of the specification is more significant than 0.5MPa, and the dry-wet splitting strength ratio is more excellent than 75%. Therefore, regardless of the amount of RAP, the water stability of cold recycled asphalt mixture can meet the requirements of road performance. Overall, light oil recycling agent can effectively improve the water stability of recycled asphalt mixture and effectively slow down the water damage of recycled asphalt.

5. CONCLUSIONS

Based on the low utilization rate of aged asphalt, a cold regenerant was prepared by diluting and dissolving aged asphalt with a light oil regenerant. The regenerant comprised light base oil, stabilizer, plasticizer, penetrant, and anti-aging agent. Through the asphalt performance test and mixture mechanics and performance test, the ratio of regenerant and regeneration effect was studied. The main conclusions are as follows.

(1) Through the 60 °C kinematic viscosity, mass loss before and after aging and three significant indicators to determine the ratio of regenerant ratio, light base oil: plasticizer: stable balance agent: penetrant: anti-aging agent ratio of 80:20:25:8:5. The performance of the regenerant and the performance index of the recycled asphalt can meet the requirements, and it has good anti-aging performance.

(2) A thermogravimetric analysis test found that the prepared regenerant has a high aromatic content and a low asphaltene content, which can well adjust the four-component balance of aged asphalt. Comparing recycled asphalt with aged asphalt, the contents of saturated and aromatic components are increased, while the contents of resin and asphaltene are decreased. The four-component content of asphalt adjusted by regenerant is close to that of new asphalt.

(3) Through the 15 °C splitting test and compressive test, it is found that after adding the regenerant, the splitting strength and compressive strength of the emulsified asphalt cold recycled mixture at 15 °C are improved, indicating that the appropriate amount of regenerant can improve the cohesion of the cold recycled mixture, thereby improving its mechanical properties. When the regenerant content is 0.9%, the mechanical properties are the best.

(4) The road performance of the recycled mixture has been dramatically improved after using a light oil regeneration agent. With increased RAP content, the high-temperature stability of the recycled mixture will decrease. However, no matter how much RAP content is, the dynamic stability of cold recycled asphalt mixture can meet the requirements of road performance. The water stability and low-temperature crack resistance of recycled mixture increase with increased RAP content.

6. ACKNOWLEDGMENTS

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