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Research and Application of Green Environmental Cold Mix Asphalt Mixtures for Township Roads

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Abstract:

In this study, oleic acid and a water-based cold mix agent were introduced to prepare cold mix asphalt. AC-13 was selected as the aggregate gradation for the mixture design, with the optimal asphalt-to-aggregate ratio determined to be 4.9%. Additionally, cement was incorporated to replace part of the mineral powder, further improving the pavement performance of the cold mix asphalt mixture. The cold mix cold paving asphalt mixture was cured at 110°C, and its pavement performance was tested. The results showed that the modified cold mix cold paving asphalt mixture exhibited excellent road performance, with a dynamic stability exceeding 1500 times/mm, a water immersion residual stability strength ratio greater than 80%, a freeze-thaw splitting test residual strength ratio over 70%, and a scattering loss rate of less than 10%. The material was trial-paved in a factory area in the High-tech Zone of Zhengzhou, Henan Province, in July 2023. The current road conditions are performing well, further demonstrating the strong potential of this technology for widespread application.

Keywords: Green environmental protection, township roads, cold mix asphalt mixture, reactive diluent, asphalt pavement, pavement performance.

1. Introduction

As ecological resources become increasingly depleted and environmental pollution intensifies, green, environmentally friendly, energy-saving, and emission-reducing technologies have emerged as key areas of research across various industries. By the end of 2023, China's total highway mileage will reach 5.441 million kilometers, an increase of 91,000 kilometers compared to the end of 2021. The total mileage and density of highways in China have steadily risen each year, with township roads accounting for more than 50% of this total [1]. Highway construction consumes vast quantities of asphalt mixtures, with traditional high-energy consumption and high-pollution hot-mix asphalt mixtures making up about 99% of the total, approximately 600 million tons annually. Given that producing one ton of hot-mix asphalt emits 40 kg of carbon dioxide, total CO2 emissions amount to a staggering 24 million tons per year [2].

In contrast, the mixing temperature of cold-mix cold-paved asphalt mixtures does not exceed 100°C, and the construction process occurs at room temperature. This technology reduces energy consumption by about 70% and VOC emissions by roughly 90%. It offers numerous advantages, including energy savings, environmental protection, lower overall costs, good road performance, and ease of construction [3]. In line with the state and the Ministry of Transport's clear requirements to improve asphalt pavement quality and reduce energy consumption, cold-mix cold-paving technology supports green development, fosters the coordinated growth of highway transportation and ecological protection, deepens the construction of green highways, and promotes the conservation and efficient use of resources and energy.

Foreign developed countries began studying cold-mix mixtures in the 1920s and 1930s, with the former Soviet Union and the United States being the most notable. Their successful storage mixtures were suitable for both road base construction and repair work [4]. Liao and his team explored the relationship between the viscosity changes of solvent-based cold-mix cold-paved asphalt and the strength development of cold-mix asphalt mixtures. Their research indicates that, under a curing condition of 110°C for 24 hours, the road performance of cold-mix asphalt mixtures after full curing can be reliably predicted. The team also recommended a viscosity of 13 Pa·s for the asphalt [5].

The former Soviet Union conducted extensive research on cold-patch asphalt mixtures in the 1950s, using diluted asphalt as the primary binder and employing a hot-mix cold-patch process. A distinctive feature of this approach was the use of a high mineral powder content, ranging from 15% to 30%. It was believed that increasing the mineral powder content and reducing the asphalt content would create a very thin asphalt film within the mixture, thereby enhancing the bonding strength and improving the asphalt mixture's overall strength [6].

The United States' SHARP program carried out the most extensive experimental research on pavement maintenance in history. The cold-mix cold-laid asphalt mixtures developed in the U.S. primarily use diluted asphalt as a binder, valued for its low cost and transportation ease. As a result, cold-mix asphalt remains a popular product, with users typically producing the mixture themselves [7].

China began studying cold-mix cold-laid asphalt mixtures in the 1980s. Researchers like Li Jiusu successfully produced cold-mix asphalt by adding unsaturated fatty acids to diluted asphalt [8]. Zhao Shichao from Beijing University of Architecture and Civil Engineering conducted in-depth research on new cold-mix emulsified asphalt mixtures. His findings showed that adding a suitable amount of cement allows the performance of cold-mix emulsified asphalt mixtures to approach that of hot-mix asphalt mixtures of the same grade [9].

This paper presents a reactive cold-mix asphalt that significantly reduces the viscosity of asphalt, enabling low-temperature mixing. Additionally, the incorporation of cement during the mixing process results in an asphalt mixture with excellent road performance.

2. Raw Materials

The raw materials used in the study include 70# matrix asphalt, cold mix agent of Henan Jiuyi Environmental Protection Technology Co., Ltd., oleic acid, aggregate, cement, filler, and the aggregate is made of limestone with high wear resistance, high adhesion, low water absorption, and low needle-like flakes. The coarse aggregate specifications are 5-10mm and 10-15mm, and the fine aggregate specifications are 0-5mm. The filler is dry and clean mineral powder made by fine grinding of limestone. The technical indicators of coarse and fine aggregates and fillers all meet the technical requirements of the Technical Specifications for Highway Asphalt Pavement Construction (JTG F40-2004) [10].

2.1 The Preparation and Properties of Cold Mix Agents

The cold mix agent is a comprehensive additive for preparing cold mix cold paving asphalt mixture developed by Henan Jiuyi Environmental Protection Technology Co., Ltd. The cold mix agent consists of a diluent emulsion and a modifier. The diluent emulsion is an oil-in-water emulsion formed by the diluent, emulsifier, and a small amount of water. The diluent can be any one or a combination of substances such as diesel, naphtha, solvent oil 120, solvent oil 200, fatty esters, or petroleum ether. The emulsifier can be any one or a combination of substances such as glyceryl monostearate or propylene glycol fatty acid esters. The modifier in the cold mix agent is typically one or a combination of substances such as rubber oil, styrene-butadiene-styrene block copolymer (SBS), or styrene-butadiene rubber (SBR) [11]. As shown in Figure 1, when observed under an Olympus microscope, the asphalt mixture is mainly in an oil-in-water state, with the oil phase dispersed in the water phase as droplets smaller than 50μm, and the dispersion system is relatively stable.

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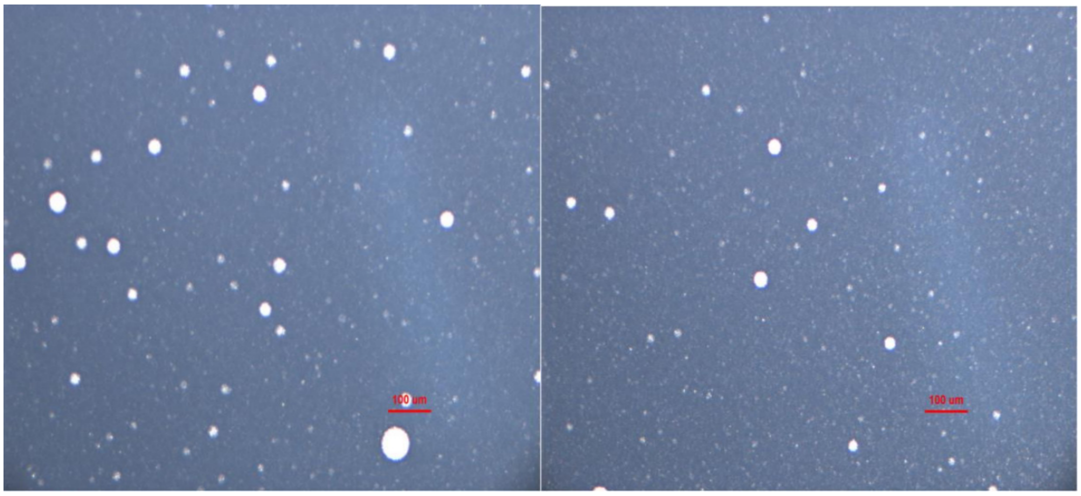

Fig.1 Dispersion picture of cold mix under microscope

2.2 Cold Mix Asphalt

2.2.1 Optimal Dosage of Oleic Acid

The viscosity of asphalt is an important indicator that directly affects the cohesiveness, construction workability and stability of cold-mix asphalt mixture. When the viscosity is low, the asphalt is easy to mix and has excellent workability, but it is not conducive to the formation of its strength; when the viscosity is too high, it will affect the construction and workability. Taking 70# road petroleum asphalt as the basic material, the base asphalt is heated to about 110°C, a water-based cold mix agent is added at a ratio of 2%, and then oleic acid is added at a ratio of 20%, 25%, 30%, and 35%. After stirring evenly, it is cold-mix asphalt. The optimal amount of oleic acid added is determined by the 60°C dynamic viscosity. The test results are shown in Table 1. The oleic acid addition ratio that can be selected for comprehensive cost is 25% of the asphalt.

Table 1. Rotational viscosity of cold mix asphalt at 60℃

Oleic acid dosage /%	Rotational viscosity at 60℃/Pa·s
20	7.83
25	6.03
30	2.79
35	1.85

2.2.2 Preparation process and technical indicators of cold mix asphalt

Heat 70# road petroleum asphalt in an oven to approximately 110°C. Take 100 parts of asphalt, 2 parts of water-based cold mix agent, and 25-30 parts of oleic acid, and stir thoroughly to obtain the cold mix asphalt. The main technical specifications of the cold mix asphalt are shown in Table 2.

Table 2.The Main Technical Specifications of The Cold Mix Asphalt

Subjects		Units	Technical Specifications	Experimental Methods[12]
Evaporation Residue Content		%	≥80	JTG E20 T 0651
Evaporation Residue Properties	Asphalt Penetration(100g, 25℃)	0.1mm	70~100	JTG E20 T 0604
	Asphalt Extensibility(5℃,5Bm/min)	Bm	≥100	JTG E20 T 0605
	Ring and Ball Softening Point	℃	40~50	JTG E20 T 0606
Rotation Viscosity at 60℃		Pa·s	<16	JTG E20 T 0620
Adhesion to Aggregates		—	≥level 4	JTG E20 T 0654

2.2.3 Mixing Temperature Determination

In order to determine the mixing temperature and compaction temperature of cold-mix asphalt, an asphalt rotation viscosity test was conducted. The viscosity-temperature curve was drawn by measuring the viscosity change of cold-mix asphalt at different temperatures. The viscosity-temperature curve can intuitively reflect the changing trend of asphalt viscosity with increasing temperature. In the mixing process, the viscosity of asphalt is a crucial parameter. Too high viscosity will lead to uneven mixing, while too low viscosity may not ensure a good combination of aggregate and asphalt. Therefore, through the viscosity-temperature curve, a suitable mixing temperature can be found so that the asphalt has good fluidity so that it can be fully mixed with the aggregate, but it will not be too fluid to affect the formation of the asphalt film. At the same time, the asphalt mixture at this temperature should have appropriate plasticity and be able to achieve the ideal density in the subsequent compaction process.

Therefore, the mixing temperature and compaction temperature determined by the asphalt rotation viscosity test ensure that the cold-mix asphalt mixture can have stable performance during production and construction, and meet the construction requirements required for township road paving.

Temperature ℃	60	80	100
Viscosity pa.s	6.03	1.81	0.16

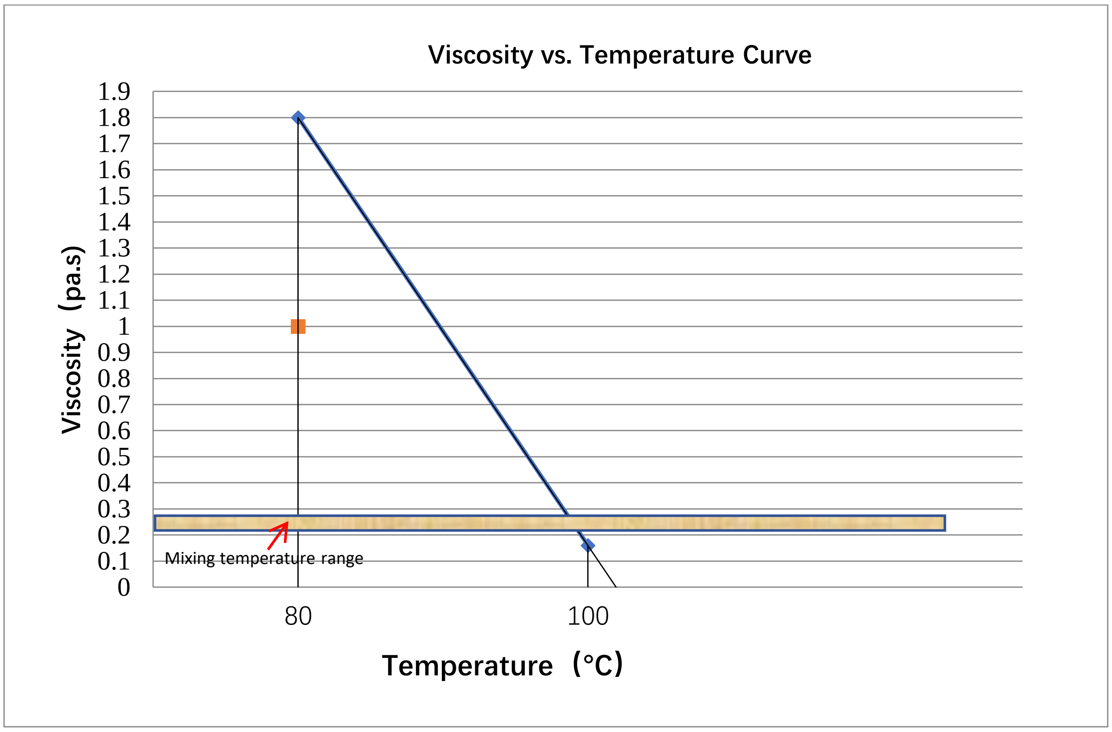

Fig.2. viscosity-temperature curve

Taking the temperature when the viscosity of petroleum asphalt is 0.17Pa.s±0.02Pa.s as the mixing temperature range, it can be seen from the figure that the mixing temperature of cold mix asphalt mixture should be 100℃±2℃.

3 Gradation Design of AC-13 Cold Mix Cold Paving Asphalt Mixture

The steps of mixture ratio design are to determine the nominal maximum particle size, mineral grading and the best oil-stone ratio. Porosity is one of the important indicators affecting the durability of the mixture. Considering the application of cold mix and cold paving, the paving of township roads, the ordinary AC-13 grading is used. See Table 3 for details:

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Table 3. AC-13 Grading Range

Gradation Type	Mass percentage (%) passing through the following sieve sizes (mm)									
	16.0	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
Gradation Upper Limit	100	100	85	68	50	38	28	20	15	8
Gradation Lower Limit	100	90	68	38	24	15	10	7	5	4
Gradation Median	100	95	76.5	53	37	26.5	24	13.5	10	6

4 Road Performance of Cold Mix Cold Paved Asphalt Concrete

4.1 Strength formation mechanism

Compared with hot-mix hot-paved mixtures, the strength of cold-mix cold-paved mixtures is gradually formed. After paving and compaction, the space between aggregates is compressed, the polymer emulsifier breaks the emulsion, the dispersed asphalt particles gather and merge, the internal friction between aggregates and the asphalt bonding force increase, and the most active components of petroleum asphalt and oleic acid on Route 70 are both polymer carboxyl acids, the polar end of which is the carboxyl group, and the passivation part belongs to the hydrocarbon group. According to the principle of chemical interaction, the hydrogen ions in the carboxyl group will exchange with the cations in the inorganic active enhancer and the mineral material to form water-insoluble cyclopentaneate and dissolve in non-polar polymer hydrocarbons and oil. At the same time, asphalt molecules and anions generate molecular forces, thereby forming initial strength. Under the influence of external conditions such as repeated rolling of vehicles and the natural environment, oleic acid and cement react chemically to accelerate curing, and the strength continues to increase; after a period of operation, the final strength of the road surface is not lower than that of hot-mix asphalt concrete.

4.2 Optimal Cement Content

In order to determine the optimal cement content in asphalt mixture, the experiment used cement to directly replace part of the mineral powder. The specific method is to replace the mineral powder with cement in different proportions (0%, 20%, 40%, 60%, 80% and 100%) to observe the effect of cement content on the performance of the mixture.

4.3 Marshall stability

4.3.1 Early strength

The early strength of the mixture determines whether the asphalt pavement will be damaged in the early stage of paving. The mixture specimens were formed by the modified molding method and placed in a 30°C water bath thermostat for 30 minutes before the Marshall stability test to evaluate whether the early strength of cold-mixed cold-paved asphalt concrete meets the specification requirements. The test results are shown in Table 4.

Table 4. Effect of Cement Content on Early Strength

	Early Strength/kN
0%	2.56
20%	3.32
40%	3.85
60%	3.98
80%	3.35
100%	3.12

4.3.2 Molding strength

The molding strength of the mixture affects its service life. After the diluent is released, there must be sufficient molding strength to ensure its basic performance. The test results are shown in Table 5.

Table 5. Effect of Cement Content on Forming Strength

Group	Molding Strength/kN
0%	8.02
20%	8.16
40%	8.37
60%	8.96
80%	8.35
100%	8.18

4.2 High Temperature Stability, Water Stability, and Freeze-thaw Splitting

In the dynamic stability test, the test specimens were prepared using the wheel rolling method. Due to the temperature sensitivity of asphalt materials, permanent deformation occurs under the combined effects of high temperature and load, eventually leading to the formation of ruts. Therefore, a rutting test is conducted to verify the high-temperature stability of the asphalt mixture. The water stability of cold mix asphalt mixtures with varying cold mix agent contents was tested using the conventional immersion Marshall test and freeze-thaw splitting test. Rutting tests were conducted on cold mix cold paving asphalt mixture specimens with cement replacing mineral powder at replacement ratios of 0%, 20%, 40%, 60%, 80%, and 100%, and their high-temperature stability was analyzed. Standard rutting test specimens were prepared according to the modified testing method, with the test temperature set to (60±1)°C and a 3-hour heat preservation period. The tire pressure for rolling met standard requirements, and the test results are shown in Table 6.

Table 6. High temperature stability and water stability of cold mix asphalt

Experimental Subject	Units	Requirement	Experimental Value						Experimental Methods
			0%	20%	40%	60%	80%	100%	
Dynamic Stability	cycles/mm	≥800	937	989	1218	1573	1435	976	JTG E20 T0709
Immersion Marchall	%	≥70	70.2	78.9	75.0	80.2	73.2	70.5	JTG E20 T0709
Freez-thaw Splitting	%	≥60	65.4	71.2	68.9	73.2	68.5	67.2	JTG E20 T0709
Scattering Loss	%	≤10	8.76	7.44	5.48	4.42	4.02	3.59	JTG E20 T0733

4.3 Summary

(1) The amount of oleic acid significantly affects the properties of cold mix asphalt. Increasing the dosage appropriately leads to greater ductility and penetration, while reducing the softening point and viscosity at 60°C, making the asphalt more suitable for cold mix cold paving operations. Based on the results of the 60°C rotational viscosity test, the cold mix asphalt with 25% and 30% oleic acid content falls within the acceptable range of 8-16 Pa·s, indicating that the optimal range of oleic acid content is approximately 25%-30%. Considering the cost and resource utilization, 25% cold mix agent content was selected for subsequent tests.

(2) The addition of cement improves the early strength, dynamic stability, and stripping resistance of the mixture. However, when the replacement rate exceeds 60%, the improvement in early strength and dynamic stability diminishes. Considering both performance and economic factors, the optimal replacement range for cement is 40%-60%, with the best replacement rate being 60%. This corresponds to a cement content of 2%-3%, with 3% being the optimal cement content.

5 Application of Cold Mix and Cold Pave

To verify the practical application value of this material and based on the results of preliminary small-scale tests, a trial paving was conducted in July 2023 in a factory area in the High-tech Zone of Zhengzhou, Henan Province.

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The test section was 90 meters long and 4 meters wide. First, the area was swept clean, ensuring no loose particles or debris. The base layer was then inspected, with local treatments carried out as necessary. Next, a layer of emulsified asphalt tack coat was sprayed, with an evaporation residue content of no less than 50% and a spray rate of 0.5 kg/m². Finally, a 4.0 cm layer of AC-13 cold mix cold paving asphalt mixture was spread. The cold mix agent used in the cold mix asphalt, provided by Henan Jiuyi Environmental Protection Technology Co., Ltd., was added at 2% of the asphalt content, oleic acid at 25% of the asphalt content, and cement at 3% of the aggregate content. The discharge temperature of the cold mix asphalt concrete was 100°C. During construction, a 12-ton double steel wheel roller was used for 1 pass of static rolling, followed by 3 passes of vibratory rolling, 2 passes of compaction with a rubber-tired roller, and finally, surface finishing with the double steel wheel roller.

6 Road Performance

When conducting a comprehensive evaluation of the pavement performance of the test section, the assessment was based on the current road construction and acceptance standards. The key performance indicators evaluated include skid resistance, pavement smoothness, water tightness, and interlayer bonding performance. The specific indicators are shown in Table 7.

Table 7.Test Results

Test Section Pavement Inspection Items	Cold mix cold paving asphalt concrete AC-13	Design requirements
Pavement Friction Coefficient (Digital Pendulum Method) BPN	59	≥40
Permeability Test (mL/min)	38	≤300
Pavement Smoothness (3-meter straightedge, mm)	1.6	5
Dynamic Stability (cycles/mm)	1987	≥800
Pavement Texture Depth Test (Electric Sand Filling Method) (mm)	1.10	≥0.55

7 Conclusion and Future Outlook

Through both small-scale and medium-scale tests, the feasibility of applying green, environmentally friendly cold mix asphalt mixtures in township roads has been successfully verified. The test results indicate that this technology has achieved significant success in terms of material performance, ease of construction, and environmental benefits, meeting the requirements for township road paving. However, there is currently a lack of unified technical standards in this field within China, which has become the primary limiting factor for the large-scale promotion of this technology. At present, efforts are being made in collaboration with industry leaders to establish relevant industry and local standards, with Henan Province working on local standards for cold mix cold paving asphalt concrete.

Looking forward, in addition to continuing to promote this technology in the township road sector, further in-depth research will be conducted, especially to develop reactive cold mix cold paving asphalt mixtures for highways and other roads with higher performance requirements. The future development of this technology will not be limited to township road applications but will expand to higher-grade road construction. By continuously optimizing the technical system and improving standardization efforts, the goal is to enhance the green and low-carbon emissions of China's road construction and contribute to the implementation of sustainable development concepts.

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