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Research on Road Performance of Asphalt Mixture with Iron Waste Ore

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Abstract: To investigate the road performance of asphalt mixtures incorporating different types of iron waste ore, aggregates derived from stripping waste rock rich in iron trioxide (Fe_2O_3) and iron oxide (FeO) were utilized. Experimental comparisons revealed that the asphalt concrete mixture containing iron trioxide mining and stripping waste rock exhibited the highest dynamic stability, indicating superior high-temperature stability. The mixture with waste rock rich in iron trioxide ranked second in terms of performance. Additionally, the residual stability of asphalt concrete mixed with mining and stripping waste rock showed a significant improvement, with the mixture containing iron trioxide-rich waste rock achieving a residual stability of up to 94.96%. Furthermore, asphalt mixtures incorporating stripping waste rock demonstrated enhanced anti-skid properties compared to conventional mixtures, with the iron trioxide-rich aggregate mixture performing the best. Measurements of texture depth indicated that these mixtures also offered improved drainage and noise reduction capabilities. In summary, replacing traditional mining gravel with mining and stripping waste rock not only provides economic benefits but also addresses the environmental issue of waste rock accumulation.

1. Introduction

As mining operations continue to expand, mining waste rock has emerged as a significant source of solid pollution, adversely impacting air, soil, and water quality. When sulfide ores in the waste rock come into contact with air, they undergo oxidation reactions, releasing harmful gases that contribute to air pollution. Additionally, fine particles of waste rock can easily dry and form dust, further degrading air quality. Under the influence of wind, sunlight, and surface runoff, harmful components from the waste rock can infiltrate the soil. These contaminants, including toxic substances and radioactive materials, can severely damage soil structure and composition. This often leads to excessive soil acidity and salinization, which negatively affect crop growth and agricultural productivity. Over time, weathering processes cause water-soluble compounds and heavy metal ions from open-pit mine waste rock to leach into surface water or groundwater through runoff or seepage, resulting in significant water pollution [1].

In order to protect the environment, extensive research and comprehensive application have been carried out in the field of mining waste recycling at home and abroad. The research on the preparation of high strength concrete after the treatment of the mine stripping waste stone has been carried out, and its comprehensive performance is also very good [2-10].Waste rock contains trace elements needed for crop growth and development, so it is made into soil conditioner [11]. This technology can also be extended to applications in sleeper and bridge construction, significantly enhancing the utilization rate of waste materials and demonstrating substantial comprehensive value [12-26]. The research scope for recycling mine solid waste is continually expanding. In this study, the road performance of asphalt mixtures incorporating two types of iron waste ore is investigated. Specifically, aggregates derived from stripping waste rock rich in iron trioxide (Fe_2O_3) and iron oxide (FeO) are used to prepare the mixtures.

2. Materials

2.1 Asphalt

Asphalt is a complex blend of various hydrocarbons and their non-metallic derivatives, formed under specific conditions. Its composition is highly intricate, exhibiting high viscosity characteristics. Leveraging these properties, asphalt can bind various coarse and fine aggregates to create a cohesive mixture. For this experiment, 90# bitumen produced by Panjin North Asphalt Co., Ltd. was utilized. The primary technical specifications of the 90# asphalt, as outlined in the *Standard Test Methods of Bitumen and Asphalt Mixtures for Highway Engineering* [27], are detailed in Table 1.

Table 1: Main technical specifications of 90# asphalt

Performance indicators		Unit	Test results	Specified value
Penetration number(25℃, 100g, 5s)		mm	87	80～100
Softening point (R&B Method)		℃	46.5	≮45.0
Ductility(5cm/min, 10℃)		cm	98.2	≮45
Ductility(5cm/min, 15℃)		cm	144.6	≮100
Density		g/cm3	1.018	actual measurement
After the RTFOT	Quality change	%	0.72	≯±0.8

2.2 Mining Waste Rock

In this study, the coarse aggregate used in the raw materials was sourced from the Dagushan iron mining area in Anshan. This mining area primarily produces two types of mining waste rock: one is iron-deficient waste rock containing iron oxide, and the other is iron-deficient waste rock containing iron trioxide. Representative samples of these materials are illustrated in Figure 1 and Figure 2 [28].

Figure 1: Waste rock containing iron trioxide

Figure2 Waste rock containing iron oxide

The stripping waste rock undergoes a two-stage crushing process using a jaw crusher. The first stage produces coarse aggregate, which is then further crushed to generate fine aggregate with a particle size of less than 4.75 mm. After crushing, a sand washing machine is used to clean the material, resulting in machine-made sand. In this experiment, two types of aggregates were prepared following the steps of initial coarse crushing followed by fine crushing. Specifically, the aggregates include stripping waste rock coarse aggregate (5 mm–20 mm) and stripping gravel fine aggregate (less than 5 mm). These aggregates were then subjected to various physical and mechanical tests. For instance, the test results for waste rock aggregate containing iron trioxide with a particle size of 16–20 mm are presented in Table 2.

Table 2: Physical properties index of waste rock aggregate containing iron trioxide

Physical property index		Crushed value (%)	Losangeles weared value(%)	Apparent relative density (g/cm^3)	Water absorption(%)	Robustness (%)	Content of needle flake particles (%)	Soft stone content (%)	Proportion of particles less than 0.075 mm(%)
Specified value [25]		≯26	≯28	≮2.6	≯2.0	≯12	≯15	≯3	≯1
16-20mm	Test results	16.2	21.3	3.283	0.81	3	12.3	0.2	—
13.2-16mm	Test results	19.2	14.312	3.254	0.83	—	10.1	0.2	0.87
9.5-13.2mm	Test results	19.8	13.312	3.240	0.66	—	12.1	2.1	0.8
4.75-9.5mm	Test results	22.4	18.01	2.921	0.93	—	14.9	1.9	0.98
2.36-4.75mm	Test results	25.2	19.1	2.516	1.12	—	13.6	—	0.99

3. Asphalt Mixture Proportioning Design

3.1 Gradation Composition Design

In this study, following the guidelines outlined in the *Technical Specification for Highway Asphalt Pavement Construction* [29], the mix proportion design for AC-20 asphalt mixture was conducted using three types of mineral aggregates: iron oxide stripping waste rock, iron trioxide stripping waste rock, and conventional limestone. The trial synthetic gradation results for these three distinct mineral aggregates are illustrated in Figure 3.

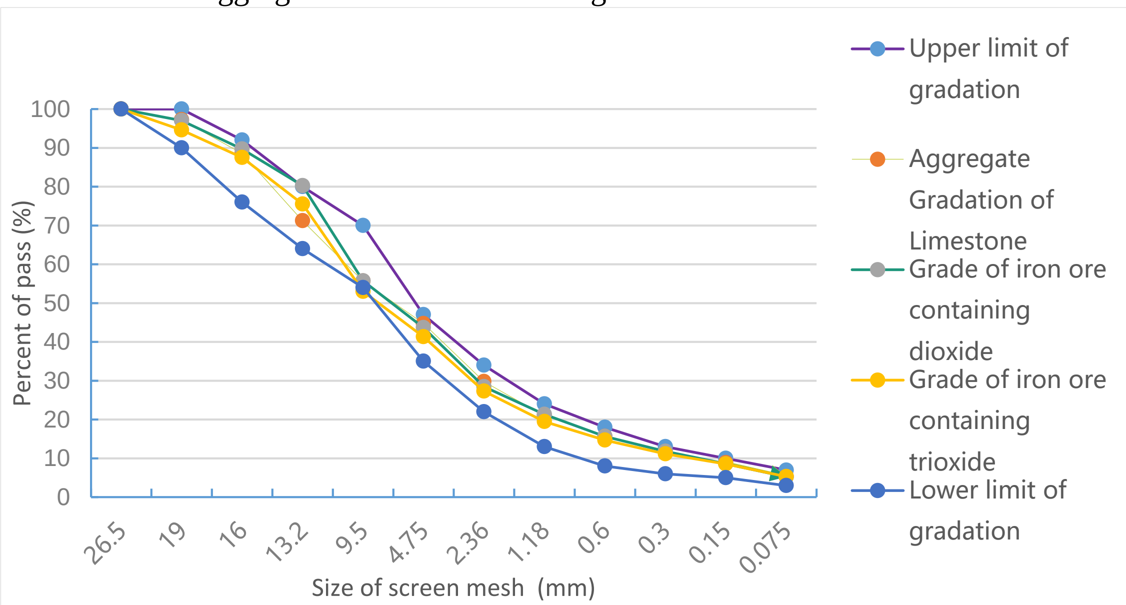

Figure 3: Trial synthetic gradation of three different mineral aggregates

3.2 Optimal Asphalt Content

This paper design the optimum oil-stone ratio by Marshall method. The optimum oil-stone ratio of three different asphalt mixtures is shown in Table 3.

Table 3: Optimum oil-stone rate of three kinds of asphalt mixtures

Oil-stone ratio index	Three kinds of asphalt mixtures		
	Fe_3O_4 waste stone asphalt mixture	Fe_2O_3 waste stone asphalt mixture	common limestone asphalt mixture
Optimum oil-stone rate (%)	4.45	4.26	4.65

4. Experimental Study on Pavement Performence of asphalt Mixture

4.1 High Temperature Stability Performance

High-temperature stability is a critical aspect of asphalt mixture performance and represents a key weakness in asphalt concrete pavement. In this research, the high-temperature stability of the three types of asphalt mixtures was evaluated using the wheel tracking test. The test specimens, measuring 300 × 300 × 50 mm, were prepared using the rolling method and subjected to a load of 0.7 ±0.05 MPa. A visual representation of the specimen is provided in Figure 4.

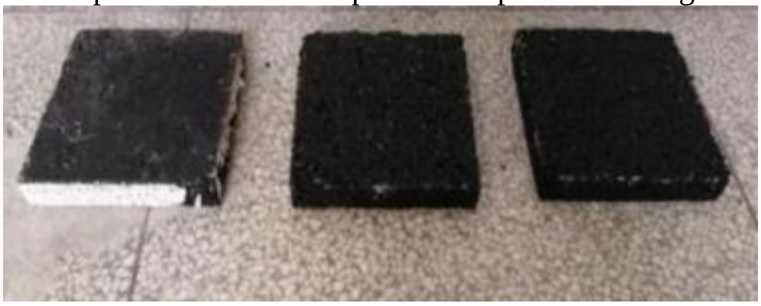

Figure 4: Test specimen for wheel tracking test

Wheel tracking test results of asphalt mixture are shown in Table 4.

Table 4: Wheel tracking test results of three kinds of asphalt mixture

Index	Fe_2O_3 waste stone asphalt mixture			Fe_3O_4 waste stone asphalt mixture			common limestone asphalt mixture		
45min displacement(mm)	1.511	1.533	1.520	1.417	1.467	1.433	1.508	1.509	1.524
60min displacement(mm)	1.832	1.822	1.861	1.731	1.720	1.742	1.961	1.896	1.953
Dynamic stability(time/mm)	1963	1954	1937	2006	2012	2009	1391	1387	1419
Relative deformation rate(%)	3.664	3.602	3.644	3.462	3.387	3.451	3.922	3.897	3.923

In the experimental study on high-temperature stability, three specimens were prepared for each type of asphalt mixture. A higher dynamic stability value indicates greater resistance to deformation at high temperatures. As shown in Table 4, the asphalt mixture containing Fe_3O_4 waste stone exhibits higher dynamic stability and a lower relative deformation rate compared to the other two mixtures under identical test conditions. Figure 5 further illustrates that the high-temperature stability of the Fe_3O_4 waste stone asphalt mixture is the best, surpassing that of the common limestone asphalt mixture by approximately 44.2%. Similarly, the Fe_2O_3 waste stone asphalt mixture demonstrates a 41.1% improvement in high-temperature stability over the common limestone mixture. Consequently, the high-temperature stability of the conventional asphalt mixture is significantly lower than that of the two waste stone mixtures. The relative deformation rate reflects the extent of deformation in the asphalt mixture under repeated high-temperature loading.

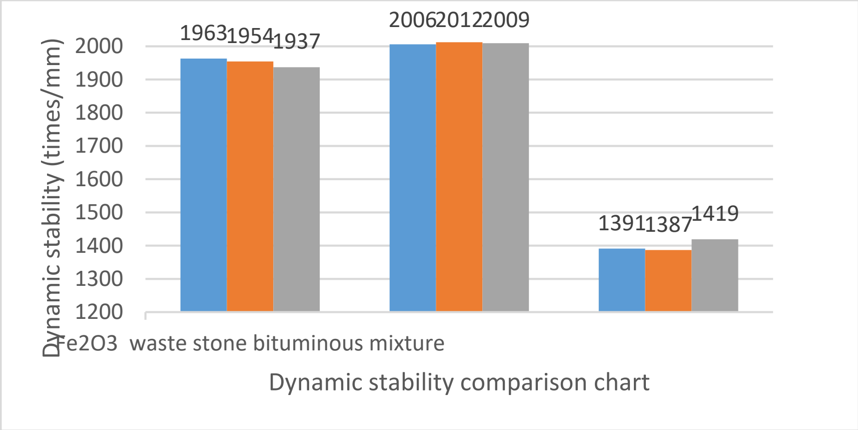

Figure 5: Dynamic stability comparison chart

The wheel tracking test results demonstrate that asphalt mixtures incorporating iron ore waste stone exhibit a significantly lower relative deformation rate compared to conventional limestone asphalt mixtures under identical testing conditions. Comprehensive analysis of both dynamic stability and relative deformation rate indicators reveals that the iron ore waste stone-modified asphalt mixtures possess superior high-temperature stability performance, particularly under elevated temperature conditions. Among the tested materials, the Fe_3O_4 waste stone asphalt mixture shows the most pronounced enhancement in high-temperature stability, establishing it as the optimal performer in this study.

4.2 Water Stability Performance

Water stability represents a crucial performance parameter for asphalt mixtures, serving as a primary determinant of their resistance to water-induced damage. In this investigation, the water stability characteristics of various rock asphalt mixtures were systematically evaluated through the immersion Marshall test, conducted in strict compliance with the Standard Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering. The experimental protocol involved the preparation of cylindrical test specimens with standardized dimensions of 101.6 mm in diameter and 63.5 ±1.3 mm in height, as depicted in Figure 6. Following specimen preparation, the samples were subjected to immersion in a precisely controlled water bath maintained at 60 ℃ for a duration of 48 hours, after which their mechanical stability was quantitatively assessed.

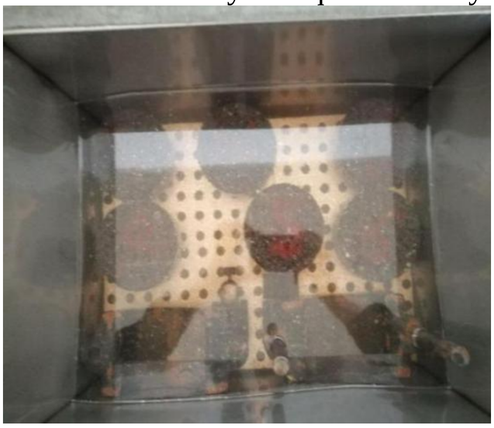

Figure 6: Constant temperature water bath immersion specimen

The immersion Marshall test results for the three asphalt mixtures are summarized in Table 5. The data reveal that both iron ore waste stone-modified asphalt mixtures not only satisfy but substantially exceed the standard requirements for residual stability, demonstrating superior performance compared to conventional limestone asphalt mixtures. Specifically, the Fe_3O_4 and Fe_2O_3 waste stone asphalt mixtures exhibit residual stability values that are 8.6% and 5.7% higher, respectively, than their conventional counterpart, with only marginal differences observed between these two modified mixtures. Notably, the Fe_2O_3 waste stone asphalt mixture demonstrates exceptional water stability performance, achieving the highest residual stability of 94.96% among the tested materials. These findings collectively indicate that the incorporation of iron ore waste stone significantly enhances the water stability characteristics of asphalt mixtures, with all tested formulations exhibiting excellent performance metrics.

Table 5: The average values of Marshall test

Index	Fe_2O_3 waste stone asphalt mixture	Fe_3O_4 waste stone asphalt mixture	common limestone asphalt mixture
40 minStability(KN)	14.2	16.82	11.26
40 hours Stability(KN)	13.56	15.56	9.85
Residual stability(%)	94.96	92.5	87.48

4.3 Skid Resistance

The skid resistance characteristics of asphalt pavement represent a critical safety parameter, directly influencing vehicular traction and traffic safety. From a materials engineering perspective, the anti-skid performance of road construction materials is predominantly determined by several key factors: the macrotexture (structural depth), microtexture (polishing value), and morphological characteristics (particle size and shape) of mineral aggregates, along with their processing methodologies. In this investigation, the frictional properties and surface texture characteristics of various asphalt mixtures were quantitatively assessed through standardized testing protocols. The coefficient of friction was measured using a precision pendulum tester, while the macrotexture was evaluated through structural depth measurements obtained with an electric sand spreader, as illustrated in Figure 7 and Figure 8, respectively.

Figure 7: Friction coefficient test

Figure 8: Structure depth test

The skid resistance performance of asphalt concrete can be assessed by analyzing its comprehensive friction coefficient and structural depth. According to the test data in Table 6, the asphalt mixture containing Fe_2O_3 waste stone exhibits the best skid resistance, though its performance is only slightly better than that of the mixture containing Fe_3O_4 waste stone. The structural depth of the Fe_2O_3 waste stone mixture and the Fe_3O_4 waste stone mixture is 19% and 14.3% higher, respectively, compared to the common limestone asphalt mixture. However, the difference in friction coefficient between the three mixtures is minimal.

4.4 Road Performance Analysis of Three Asphalt Mixtures

In this section, the efficacy coefficient method is applied to compare the test indicators of waste stone asphalt mixtures and common limestone asphalt mixtures for a comprehensive evaluation of road performance. As shown in Table 6, the efficacy coefficient of the common asphalt mixture is the lowest, indicating that its overall road performance—encompassing high-temperature stability, water stability, and skid resistance—is inferior to that of the iron ore waste stone asphalt mixtures.

Table 6: Efficiency coefficient of three types of asphalt mixture

Types	High temperature stability	Water stability	Skid-resistance	Efficiency coefficient
Fe_2O_3 waste stone asphalt mixture	0.939	0.999	0.800	0.913
Fe_3O_4 waste stone asphalt mixture	0.964	0.933	0.840	0.912
Common limestone asphalt mixture	0.626	0.799	0.880	0.768

5. Conclusion

This study investigates the road performance and influencing factors of AC-20 asphalt mixtures incorporating iron ore waste stone. Through experimental analysis, the high-temperature stability, water stability, and skid resistance of three mixtures—common limestone asphalt mixture, Fe_2O_3 waste stone asphalt mixture, and Fe_3O_4 waste stone asphalt mixture—were compared. The following conclusions were drawn:

(1) Test results indicate that the Fe_3O_4 waste stone asphalt mixture exhibits the best high-temperature stability, while the Fe_2O_3 waste stone asphalt mixture demonstrates superior water stability and skid resistance.

(2) A comprehensive evaluation using the efficacy coefficient method reveals minimal differences between the two iron-containing waste stone asphalt mixtures. However, both outperform the common limestone asphalt mixture, particularly in skid resistance.

(3) Based on the overall road performance analysis, utilizing iron ore waste stone asphalt mixtures for road construction represents an effective recycling approach.

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