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Study on the high and low temperature performance of nano alumina modified asphalt mixture

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Abstract: To improve the high and low temperature performance of asphalt mixture, nano alumina was used as additive in this study. Firstly, the high temperature characteristics of asphalt mixture with different content of nano alumina were studied by rutting test and dynamic creep test. Secondly, the fatigue properties of modified asphalt mixture at different temperature were tested by indirect tensile fatigue test. Finally, the low temperature bending test and indirect tensile test were used to evaluate the low temperature performance. The results show that nano alumina can improve the high temperature and fatigue properties of asphalt mixture to some extent, while the low temperature performance decreases slightly.

Keywords: road engineering; asphalt mixture; nano alumina; high and low temperature performance; fatigue performance.

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1 Introduction

With the increase of traffic volume and vehicle axle load in China, the early diseases of asphalt pavement gradually increase, mainly including rutting, fatigue cracking and low temperature cracking (Chen et al., 2016), which reflects the lack of high and low temperature performance and fatigue performance of asphalt mixture (Zhou et al., 2013). Rutting is the permanent deformation of pavement, including the surface rutting in the surface course and the structural rutting in the base course, which reflects the ability of asphalt mixture to resist high temperature deformation. Fatigue crack is caused by frequent vehicle load on asphalt pavement, while low temperature crack is due to the decrease of flexibility of asphalt mixture in low temperature environment. The two kinds

of cracks are directly related to the tensile strain of asphalt layer. When the tensile strain of asphalt layer exceeds its threshold, cracks will occur. The cracking of asphalt layer is affected not only by load conditions and weather conditions, but also by its own material fatigue performance and low temperature performance. In order to improve the ability of pavement to resist permanent deformation and cracking deformation and reduce the cost of repair and reconstruction, researchers usually add admixtures to the pavement materials to improve the service performance of pavement materials from the source of materials (Song, 2020). Polymer as an additive to improve the mechanical properties of asphalt mixture has become a research hotspot in recent years (Sun et al., 2019; Liu et al., 2016). The polymer modified asphalt mixture has good disease resistance, which significantly improves the service level of asphalt pavement (Yan and Wang, 2020). However, high polymer price and poor compatibility with asphalt limit its application in road engineering to a certain extent (Li and Shen, 1999). Therefore, it is necessary to seek an admixture with excellent performance and high cost performance to improve the road performance of asphalt mixture.

With the rapid development of nanotechnology, nano materials are gradually used to improve the road performance of asphalt and asphalt mixture due to their unique surface effect and volume effect (Zhang et al., 2016). Huang (2009) and Sun et al. (2013) respectively applied nano bentonite and nano silica to improve the high temperature performance of dense asphalt mixture. Wang et al. (2020) found that the addition of nano silica can reduce the static strain of asphalt mixture, increase the viscosity of asphalt mixture and delay the viscoelastic deformation. Nano titanium oxide (Ye et al., 2010), nano zinc oxide (Ma and Li, 2009), nano calcium carbonate (Sun et al., 2016) and other nano materials can improve the high temperature performance of asphalt mixture and water stability. Nano alumina can improve the mechanical properties of concrete (Zhu et al., 2016).

However, due to the short research time of the application of nano materials in improving asphalt and asphalt mixture, people have only carried out preliminary research on improving the road performance of asphalt mixture. In this research direction, the main problems are as follows: the existing research mostly focuses on the impact of nano materials on the road performance of asphalt mixture, and has not carried out systematic research on its high and low temperature performance; There are few studies on the fatigue resistance of asphalt mixture with the addition of nano materials; The research on the application of nano alumina in the performance of modified asphalt mixture remains blank. In this paper, the preparation scheme of nano alumina modified asphalt mixture is proposed, and its performance is comprehensively studied, the overall design scheme is as follows:

1 Using nano alumina as admixture, multiple modified asphalt mixtures were prepared by setting different dosage.

2 The influence of the content of nano alumina on the high and low temperature performance of modified asphalt mixture is compared and analysed, and the variation laws of rutting resistance, creep performance and tensile strain with the content of admixture are put forward.

3 The relationship model between the fatigue cracking performance of modified asphalt mixture and the content of nano alumina is established to determine the content of nano alumina when the fatigue resistance of asphalt mixture reaches the optimal value.

2 Materials and methods

2.1 The raw materials

The coarse and fine aggregates are basalt, and the filler is limestone mineral powder. The mineral aggregate is shown in Table 1, which meets the technical specification for construction of highway asphalt pavement (JTG F40-2004). 70 # base asphalt is selected, and the basic indexes are shown in Table 2. The nano alumina used in this study is produced by Antai rare metal materials Co., Ltd. and its properties are shown in Table 2.

Table 1 Aggregate gradation

Mesh size/mm	*Pass rate/%*
16	100
13.2	98
9.5	80
4.75	53
2.36	40
1.18	28
0.6	20
0.3	13
0.15	9
0.075	7

Table 2 Properties of matrix asphalt and nano alumina

Asphalt index		*Value*	*Alumina index*	*Value*
25°C Penetration/0.1 mm		68	Appearance	White powder
Softening point/°C		50	Particle size/nm	80
10°C Ductility/cm		70.3	Density/(g·cm^{-3})	0.9
Residue after film oven ageing test	Quality change/%	0.61	Solubility/%	99.0
	Penetration ratio/%	72.3	–	–
	10°C Ductility	10.6	–	–

2.2 Experimental scheme

In order to improve the service performance of asphalt pavement, this paper selects the composition materials, and proposes to use nano alumina as an admixture to make a new

asphalt mixture, as well as analyses its performance. The specific experimental scheme is as follows:

1 Study the preparation technology of nano alumina modified asphalt mixture.

2 Study the effect of nano alumina on high temperature deformation performance of asphalt mixture.

3 Study the effect of nano alumina on the low temperature crack resistance of asphalt mixture.

4 Study the effect of nano alumina on the fatigue resistance of asphalt mixture.

2.3 Preparation method

In order to make nano alumina more evenly dispersed into asphalt mixture, the wet mixing method with kerosene as auxiliary solvent was adopted in this study. Firstly, a certain amount of base asphalt was heated to 150°C, and then the high-speed shear machine was used to shear it at the speed of 4000 R min^{-1}. Then 0.3%, 0.6%, 0.9% and 1.2% nano alumina were dissolved in kerosene solvent. Finally, the kerosene dissolved in nano alumina was added to the pre heated asphalt, which was heated continuously until the kerosene volatilised completely. The optimum asphalt content of asphalt mixture with different nano alumina content determined by Marshall method is shown in Table 3.

Table 3 Optimum asphalt content of asphalt mixture with different nano alumina content

Nano alumina content/%	0	0.3	0.6	0.9	1.2
Optimum asphalt content/%	4.6	4.8	4.9	5.0	5.2

2.4 Test method

2.4.1 Rutting test

There are many methods to evaluate the high temperature performance of asphalt mixture, and rut test is commonly used to evaluate the high temperature deformation resistance of asphalt mixture in China. HLR-2 rutting machine was used in this test. The size of the test piece was 30 × 30 × 5 cm, the ambient temperature was controlled at 40°C, 50°C and 60°C, and the tire pressure was 0.7 MPa.

2.4.2 Dynamic creep test

Asphalt mixture is viscoelastic material, and its high-temperature deformation is the result of creep accumulation under dynamic vehicle load. It has certain limitations to evaluate the high-temperature characteristics of asphalt mixture by rutting test. The dynamic creep test loading method is impact loading, which can better simulate the high-temperature deformation performance of asphalt mixture under different traffic loads and environmental temperatures. In order to further study the influence of nano alumina on high temperature performance of asphalt mixture, UTM-30 pavement material servo hydraulic dynamic test system is used in this test, and the specimen size is φ100 × 150 mm. Therefore, the permanent deformation of asphalt pavement occurs in the

high temperature season of 40°C and 50°C respectively. According to the characteristics of axle load in China, the axial pressure is 0.7 MPa. The test load is in the form of half sine wave, the loading time is 0.1 s, and the intermittent time is 0.9 s.

2.4.3 Indirect tensile fatigue test

Indirect tensile test can evaluate the fatigue cracking performance of asphalt mixture, so this paper selects indirect tensile fatigue test to compare the influence of different amount of nano alumina on the fatigue performance of asphalt mixture. Utm-30 servo hydraulic dynamic test system for pavement materials is used as the test instrument. The specimen size is φ100 × 63.5 mm and the loading frequency is 1 Hz. The fatigue failure of the specimen is determined by measuring the vertical deformation of the specimen. When the vertical crack occurs in the centre of the specimen due to indirect tension, the test ends. The fatigue life of the specimen depends on the stress amplitude and temperature. The test temperature is 5°C, 15°C and 25°C respectively, and the stress amplitude is 0.2 MPa and 0.3 MPa respectively.

2.4.4 Low temperature bending and indirect tensile test

The high-temperature performance and low-temperature performance of asphalt mixture often need to be balanced, so when we pay attention to the influence of nano alumina on the high-temperature performance of asphalt mixture, we should consider its influence on the low-temperature cracking performance of asphalt mixture. The lower the limit strain is, the better the low temperature performance of asphalt mixture is. In this paper, the low-temperature performance of nano alumina modified asphalt mixture is evaluated by the low-temperature failure strain in low-temperature bending test and indirect tensile test. In the low temperature bending test, the size of the trabecular specimen is 250 × 30 × 35mm, the ambient temperature is – 10°C, and the loading rate is 50 mm min^{-1}. In the indirect tensile test, the specimen is standard Marshall specimen, the ambient temperature is – 10°C, the Poisson's ratio is 0.25, and the loading rate is 1 mm min^{-1}.

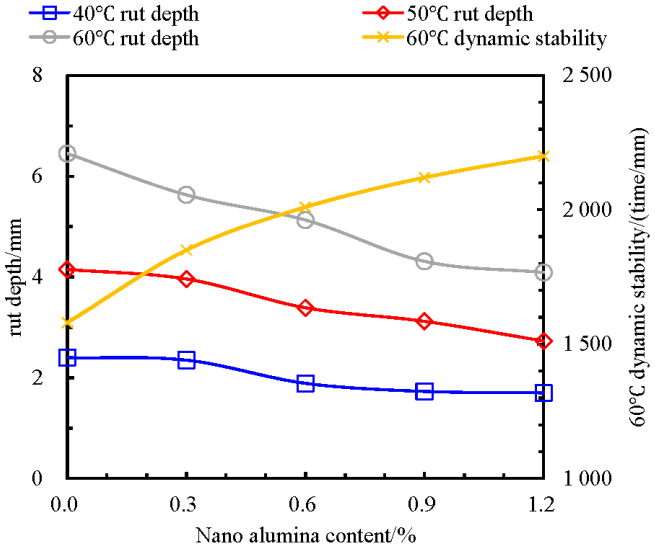
3 Results and discussion

3.1 Rutting test

Figure 1 shows the rutting test results of asphalt mixture modified with different amount of nano alumina under 0.7 MPa wheel load. The rutting depth of 60 min and dynamic stability are used to express the high temperature rutting resistance of asphalt mixture. With the increase of nano alumina content, the rutting depth of 60 min at 40, 50 and 60°C decreased gradually. This is due to the high specific surface area of nano alumina. Adding nano particles into asphalt can agglomerate asphalt, improve the viscosity and adhesion of asphalt, and reduce its sensitivity to high temperature. The dynamic stability increases with the content of nano alumina, which is also related to the viscosity of asphalt. When the nano alumina content is in the range of 0.3–1.2%, the rutting depth

of modified asphalt mixture decreases by 12.7–36.6%, and the dynamic stability increases by 17.1–39.2%. Therefore, nano alumina can improve the high temperature rutting resistance of asphalt mixture.

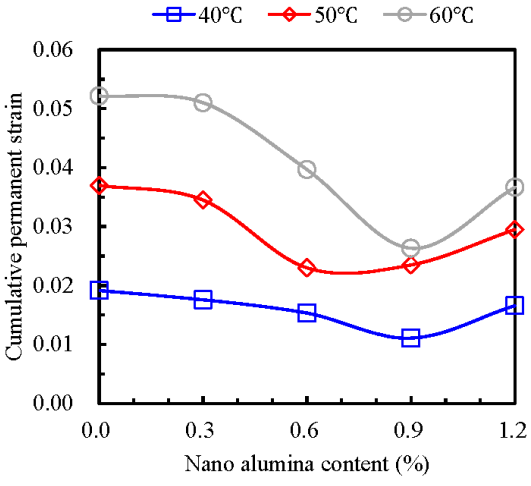
Figure 1 Rutting depth and dynamic stability (see online version for colours)



3.2 Dynamic creep test

The dynamic creep test results at different temperatures are shown in Figure 2. The cumulative permanent strain can reflect the high temperature deformation performance of asphalt mixture. The strain in the figure is the final strain after the strain tends to be stable after 4000 times of loading. The higher the ultimate strain is, the more sensitive the specimen is to high temperature environment. Under the three temperature conditions, the final strain first decreases and then increases with nano alumina, which is slightly different from the rutting test. At 60°C, 0.9% nano alumina can make the final strain of asphalt mixture reach the lowest, which is 49.5% lower than that of the specimens without nano alumina. At 40°C and 50°C, the optimal content of nano alumina is 0.9% and 0.6%, respectively. On the whole, adding 0.3–1.2% nano alumina can reduce the final strain by 2.2–49.5%. In this paper, nano alumina is used to modify hot mix asphalt mixture. Firstly, nano alumina modified asphalt reduces the heat sensitivity of asphalt, and then improves the adhesion between asphalt mortar and mixture, so as to improve the creep performance and permanent deformation performance of asphalt mixture. When the content exceeds a certain amount, nano alumina has a negative effect on the high temperature performance of asphalt mixture. Therefore, although nano alumina can improve the high temperature performance of asphalt mixture, its content should not exceed 0.9%.

Figure 2 Cumulative permanent strain (see online version for colours)



3.3 Indirect tensile fatigue test

Figure 3 shows the effect of nano alumina content on the fatigue life of asphalt mixture at different temperatures. At lower temperature and stress, the fatigue loading times of asphalt mixture are more. When the ambient temperature is 5°C and the stress is 0.2 MPa, the maximum loading times of the specimen without nano alumina is 78,000; however, when the temperature is 25°C and the stress is 0.3 MPa, the maximum loading times of the specimen is only 5200, which indicates that the temperature and stress have a great influence on the fatigue life of asphalt mixture. Lower ambient temperature and stress level can prolong the fatigue life of asphalt mixture, but the road ambient temperature and internal stress of pavement structure cannot be changed. Therefore, reducing the sensitivity of asphalt mixture to temperature and stress is a way to improve the service life of asphalt mixture, and the application of nano alumina is based on this. Under all temperature and stress conditions, the fatigue life of asphalt mixture always increases first and then decreases with the content of nano alumina. The allowable loading times of asphalt mixture with 0.6% nano alumina is the highest, which is 4.0–45.8% higher than that without nano alumina. Therefore, the addition of nano alumina can prolong the fatigue life of asphalt mixture, which also shows that nano alumina has a certain role in preventing the fatigue cracking performance of asphalt mixture.

3.4 Low temperature bending and indirect tensile test

Figure 4 shows that the tensile strain decreases with the increase of nano alumina content in low temperature bending test. The reason is that the addition of nano alumina powder reduces the light components in the base asphalt and increases the brittleness of asphalt, which leads to the decrease of low temperature performance of asphalt mixture. When the strain is less than 0.6%, the maximum strain decreases. When the tensile strain of the modified asphalt at low temperature is 1.6%, it is similar to that of the asphalt at low temperature. Nano alumina affects the low temperature performance of asphalt mixture,

but it can still meet the requirements of low temperature crack resistance of asphalt pavement in non severe cold area.

Figure 3 Fatigue life of asphalt mixture (see online version for colours)

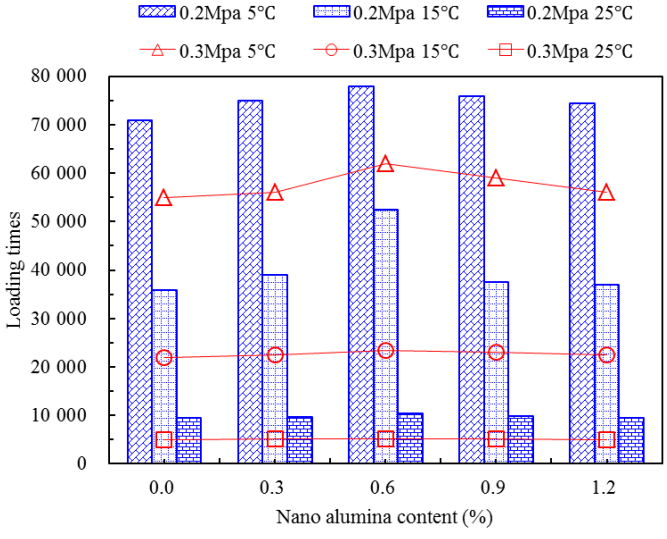
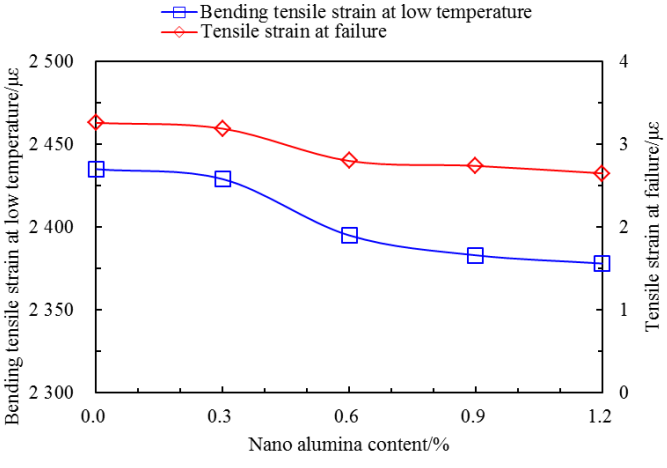


Figure 4 Ultimate strain at low temperature (see online version for colours)



4 Conclusion

In this paper, the influence of nano alumina on high and low temperature performance of asphalt mixture is evaluated through rutting test, high temperature creep test, indirect tensile fatigue test, low temperature bending test and indirect tensile test. The main results are as follows.

1 Nano alumina can improve the resistance of asphalt mixture to high temperature rutting deformation, and the resistance to rutting deformation increases gradually with the increase of its content.

2 The high temperature creep test verifies that nano alumina can improve the high temperature performance of asphalt mixture. The addition of nano alumina can reduce the final strain of asphalt mixture. There is an optimal creep property, and the optimal content of nano alumina should be less than 0.9%.

3 Nano alumina can improve the fatigue cracking performance of asphalt mixture, and the fatigue cracking performance first increases and then decreases with the content of nano alumina. When the content is 0.6%, the fatigue performance of asphalt mixture is the best, which is 4–45.8% higher than that of the sample without alumina.

4 The results show that the low temperature performance of asphalt mixture with nano alumina decreases, and the low temperature flexural strain and failure tensile strain decrease with the increase of nano alumina content.

5 Considering the influence of nano alumina on high and low temperature and fatigue performance of asphalt mixture, nano alumina can be used for modified asphalt mixture, and the optimal technical ratio of nano alumina is 0.6%.

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