

Research progress on the application of nanomaterials in asphalt pavement

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Abstract: Asphalt modified by nanomaterials can improve the road performance of asphalt pavements, and nanomaterial-modified asphalt has attracted increasing attention. This paper summarizes the research status and progress of nanomaterial-modified asphalt, and introduces its superior properties from the perspectives of modified asphalt and modified asphalt mixtures. Based on existing domestic and international studies, it outlines the key problems and research deficiencies of nanomaterial-modified asphalt, and proposes future research directions and application prospects for asphalt modified with nanomaterials.

Key words: nanomaterials, modified asphalt, asphalt pavement, composite type, dispersibility

1. Introduction

With the continuous advancement of nanotechnology, the optimization of the properties of traditional materials via nanotechnology has proven to be a promising research topic. In the field of building materials, a series of practical applications and researches have been carried out at home and abroad. Scholars have conducted in-depth studies on polymer materials and nano-coatings and achieved abundant results. In recent years, such nanotechnology concepts have also been actively introduced and applied in road construction. Nano-modified asphalt has become a research hotspot in asphalt pavement research. Its preparation method is to disperse nano-powders into base asphalt by agitators and shear instruments. Benefiting from the unique physical characteristics on the surface of nano-particles, nano-modified asphalt possesses excellent road performance, such as high and low temperature stability and anti-aging property.

The excellent performance of nano-modified asphalt largely depends on the microstructural bonding between nanomaterials and asphalt, which is its biggest distinction from other modified asphalts. As nanomaterials fall within the mesoscopic scale, they exhibit surface effect, small-size effect and macroscopic quantum tunneling effect, differing from conventional materials. Nano-particles feature extremely high atomic surface activity and readily bond with other atoms to reach a stable state, thereby improving asphalt performance from a microscopic perspective. At present, most nano-particles have realized large-scale industrial production at low cost, laying solid foundations for their application as novel asphalt modifiers. Accordingly, this paper reviews domestic and international research status and advances of nanomaterial-modified asphalt, summarizes relevant laws, puts forward innovative research directions, and delivers an in-depth prospect for research in this field.

2. Nano-modified asphalt and asphalt mixtures

2.1. Research on properties of nano-modified asphalt

At present, inorganic non-metallic nanomaterials are commonly adopted to prepare nano-modified asphalt, mainly including oxides and carbonates such as nano-SiO₂, TiO₂, CaCO₃, ZnO, Fe₂O₃ and nano-montmorillonite. Compared with other metallic materials, inorganic non-metallic nanomaterials can endow asphalt with complementary physical properties including wear resistance and anti-aging capacity. Therefore, inorganic non-metallic nanomaterials have become a research focus in the field of nano-modified asphalt, and numerous experimental studies have been conducted on them so far.

Ma Feng adopted nano-calcium carbonate in his research and verified that the performance of asphalt was improved after incorporating nano- CaCO_3 [1]. Zhang Jinsheng et al. synthesized spherical nano- Fe_3O_4 particles via chemical methods, and the addition of such particles significantly enhanced the high and low temperature performance of asphalt [2]. Zhang Chunqing et al. modified asphalt with rutile nano- TiO_2 with an average particle size below 50 nm. The test results demonstrated that nano- TiO_2 modified asphalt possessed favorable high-temperature performance and ultraviolet resistance [3]. Khodary et al. investigated the performance of asphalt modified with nano cement kiln dust (10–100 nm particles obtained by ball milling), and the penetration and softening point of modified asphalt were improved [4]. Li Yuxia et al. added nano zinc oxide rods synthesized by hydrothermal reaction into coal tar pitch, achieving remarkable improvement in the properties of coal tar pitch [5].

2.2. Research on performance of nano-modified asphalt mixtures

The performance of asphalt pavement is directly related to asphalt mixtures, which consist of asphalt and mineral aggregates. Asphalt with superior performance can effectively promote the overall performance of asphalt mixtures. Therefore, the reliability of nano-modified asphalt needs to be verified through road performance tests of asphalt mixtures. For this reason, numerous scholars have carried out extensive research on nano-modified asphalt mixtures.

Liu Daliang et al. analyzed the influence of nano-calcium carbonate modified asphalt on the performance of asphalt mixtures through road performance tests, and found that the high-temperature performance of asphalt mixtures mixed with nano-calcium carbonate modified asphalt was improved [6]. Ye Chao et al. prepared asphalt mixtures with nano- TiO_2 modified asphalt, and analyzed whether the particle size of nano- TiO_2 would affect its optimal dosage in modified asphalt and mixtures [7]. Huang Weirong et al. conducted a series of road performance tests on asphalt mixtures and confirmed that the high-temperature stability and water resistance of mixtures containing nano-modified asphalt were enhanced [8]. Jiang Haitao carried out a series of tests including indirect tensile tests, and compared the relationship between asphalt concrete blended with nano organic montmorillonite modified asphalt and its dynamic mechanical properties by virtue of fatigue equations [9].

3. Composite polymer-nano modified asphalt and its mixtures

3.1. Research on nano-composite modified asphalt

Scholars have conducted early research on polymer-modified asphalt and achieved abundant results, which have been widely applied in practical engineering. Polymer-modified asphalt is a mixed system formed by polymers swelling in asphalt, enabling modified asphalt to acquire partial properties of polymers. Commonly used polymers include SBS, SBR, PE and so on. At present, the swelling modification mechanism of asphalt by polymer materials is the most widely recognized. Nano-particle/polymer composite modified asphalt can be prepared by mixing nanomaterials and polymer macromolecules with asphalt. Studies have shown that the comprehensive performance of nano-particle/polymer composite modified asphalt is further improved compared with base asphalt.

Li Xuefeng et al. prepared nano- ZnO /SBS modified asphalt with spherical nano- ZnO particles and SBS. Performance tests proved that both asphalt and asphalt mixtures containing nano- ZnO particles achieved enhanced performance [10]. Liu Daliang et al. studied CaCO_3 /SBS composite modified asphalt and found that its softening point and penetration index rose with the increase of nano- CaCO_3 content, while its ductility at 5 °C declined [11]. Sun Lu et al. separately prepared single modified asphalt using nano- SiO_2 of different dimensions, nano organic bentonite and SBS, as well as composite modified asphalt combining nanomaterials with SBS. Comparative tests revealed that composite modified asphalt mixtures exhibited superior comprehensive performance [12]. The TiO_2 /SBS composite modified asphalt developed by Ye Chao et al. possessed outstanding high-temperature performance; meanwhile, the rutting resistance factor of nano- TiO_2 composite modified asphalt mixtures increased greatly with negligible variation of fatigue factor [13].

3.2. Research on nano-composite modified asphalt mixtures

To further verify and investigate the excellent performance of nano-composite modified asphalt, many scholars have applied it to asphalt mixtures in practical research. The advantages and disadvantages of nano-composite modified asphalt can be reflected in the road performance test results of corresponding mixtures, which has aroused extensive research on nano-composite modified asphalt.

Chang Haizhou et al. determined the relationship between the temperature characteristics of CaCO_3 /SBS composite modified asphalt and the dosage of nano- CaCO_3 through asphalt mixture tests [14]. Yang Chenguang et al. verified that ZnO/rubber powder composite modified asphalt exhibited excellent high and low temperature performance [15]. Sun Lu et al. prepared two types of composite modified asphalt by blending nano- SiO_2 , bentonite and SBS with base asphalt, and confirmed that composite modified asphalt mixtures possessed favorable high-temperature stability [12]. Sun Pei et al. conducted a series of mixture tests and found that nano-ZnO/ TiO_2 /SBS composite modified asphalt mixtures outperformed base asphalt mixtures in terms of high and low temperature performance, indirect tensile property and durability [16].

4. Research on modification with multi-dimensional nanomaterials

4.1. Overview of variable-size and morphology nano-modified asphalt

Although extensive research on nano-modified asphalt has been carried out and fruitful achievements have been obtained, most of the above studies only incorporated nano-powders with a single particle size or crystal form into asphalt to evaluate the variation in asphalt performance. Little systematic research has been conducted on the effects of nanomaterials with different particle sizes and morphologies on asphalt properties. Recently, many scholars have blended powders of varying particle sizes or crystal types into asphalt, and tested the road performance of the resulting modified asphalt and asphalt mixtures, so as to analyze and evaluate the influence laws of nanomaterials with different particle sizes or crystal forms on the aging performance of asphalt and asphalt mixtures.

Nanomaterials can form diverse morphologies under different reaction conditions. Existing research indicates that the particle size of nanoparticles has a certain correlation with the tensile strength, elastic modulus and tensile yield stress of composite materials, which can also be reflected in nano-modified asphalt. Smaller nanoparticles feature larger total specific surface area and more sufficient contact with asphalt matrix. Therefore, some domestic and foreign scholars have taken nanomaterials with different particle sizes and morphologies into consideration for asphalt modification.

4.2. Study on nano-size and crystal modified asphalt

Shen et al. took the rotational speed of ball mill as an indicator of the particle size of nano-slaked lime in experiments. Nano-slaked lime particles prepared at different rotational speeds were incorporated into asphalt at the same dosage. Afterwards, DSR tests and freeze-thaw splitting tests were adopted to evaluate and analyze the influence rules of nano-slaked lime with different particle sizes on the properties of asphalt and asphalt mixtures [17].

Aboelkasim et al. discussed the effects of nano-slaked lime with different particle sizes (50 nm, 100 nm and conventional nano-slaked lime) and different dosages on the properties of modified asphalt. Firstly, DSR test results were analyzed to explore the influence law of nanomaterials with various particle sizes and dosages on the high-temperature performance of modified asphalt. Finally, SFE tests were adopted to evaluate the effect of particle size on the surface adhesion between asphalt and aggregate [18-19].

In terms of the morphology of nanomaterials, it is well known that nano- TiO_2 possesses excellent ultraviolet shielding capacity. Nevertheless, few literatures have taken into account the influence of nano- TiO_2 with different crystal forms on the ultraviolet resistance of asphalt. Therefore, Li Xin carried out a comprehensive discussion on this subject in his thesis. He analyzed the effects of nano- TiO_2 with various dosages and crystal types on the anti-ultraviolet aging performance of asphalt by investigating the property variation of asphalt after ultraviolet irradiation of different durations and intensities [20].

Overall, nanomaterials have attracted attention in the field of road engineering. With in-depth research, nanomaterials will endow asphalt with many novel functional properties. It is believed that nanomaterials possess broad development space and promising application prospects in pavement engineering.

5. Conclusion

Experimental studies show that nanomaterial-modified asphalt achieves remarkable performance improvement, whether nanomaterials are added directly to base asphalt or blended with polymers before incorporation. However, existing studies involve a wide variety of nanomaterials without systematic investigation, and universal laws have not yet been summarized. Furthermore, the compatibility between nanomaterials and asphalt is a critical issue. Most conventional nanomaterials exhibit poor compatibility with asphalt, accompanied by severe nanoparticle agglomeration. Current technical methods cannot uniformly disperse nanoparticles as individual particles within asphalt. Therefore, the authors propose two research orientations: developing effective approaches to solve the dispersion problem of nanomaterials in asphalt, or systematically exploring blending technologies for nanomaterials and polymers in asphalt to comprehensively enhance the performance of asphalt and asphalt mixtures. In addition, systematic research should be conducted on nanomaterials with different particle sizes and morphologies to identify the optimal particle size and morphology for maximizing asphalt modification effects. Although such research incurs relatively high costs, its potential economic benefits remain incalculable at present.

6. References

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