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Research on the Pretreatment Process of Rubber Powder for Modified Asphalt Applications

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ABSTRACT: The application of rubber powder in modified asphalt has garnered significant attention in the field of road engineering and materials science. This paper discusses the advantages and methods of pretreating rubber powder in the process of modified asphalt application, including thermal mechanical method, chemical method, microwave radiation method, supercritical fluid induction, and biological method. By breaking the sulfur cross-linking bonds of rubber powder, increasing its surface activity, improving its dispersibility and reactivity, rubber powder modified asphalt shows significant improvements in high-temperature stability, low-temperature crack resistance, storage stability, and anti-aging performance. Future research should focus on optimizing pretreatment technology, improving desulfurization efficiency, and enhancing economic and environmental benefits to fully leverage the potential of rubber powder modified asphalt.

KEYWORDS: Rubber powder modified asphalt; Pretreatment methods; Thermomechanical method; Chemical method; Microwave radiation method; Supercritical fluid induction; Biological method

I. INTRODUCTION

In the field of road engineering and road materials science, the application of rubber powder modified asphalt is gaining increasing attention. Firstly, the incorporation of rubber powder significantly enhances the high-temperature stability and low-temperature crack resistance of asphalt, effectively reducing pavement cracking and extending the service life of roads. Secondly, the use of rubber powder processed from waste tires not only solves environmental issues and achieves resource recycling but also aligns with the concept of sustainable development. Furthermore, rubber powder modified asphalt can reduce traffic noise and vibration, thereby enhancing the comfort of driving. From an economic perspective, the use of rubber powder modified asphalt reduces the disposal costs of waste tires and the paving expenses for roads, offering significant economic benefits. Additionally, this material improves the low-temperature performance and viscosity of asphalt, enhances water stability, and boosts resistance to aging and fatigue. Rubber powder modified asphalt demonstrates immense potential in enhancing road performance, reducing maintenance costs, environmental protection, and resource recycling, making it an ideal material for road construction.

With the more and more extensive application of rubber powder modified asphalt, the amount of rubber powder in asphalt is also increasing, and the production difficulty of rubber powder modified asphalt is also increasing. Higher rubber powder content can lead to uniformity issues in mixing rubber powder with asphalt, requiring higher temperatures and longer times to ensure even dispersion and reaction of rubber powder in asphalt. Additionally, high rubber powder content can make the storage of rubber powder-modified asphalt difficult, leading to phase separation. In order to solve these problems, the added rubber powder usually needs to be desulfurized in advance. ^[1]

II. ADVANTAGES OF RUBBER POWDER PRETREATMENT

Currently, in the process of applying rubber powder to modified asphalt, waste tire rubber powder is usually pretreated through desulfurization to improve compatibility with asphalt, increase the addition amount of rubber powder in asphalt, and enhance the performance of rubber powder-modified asphalt.

2.1 Improving Compatibility between Rubber Powder and Asphalt

Desulfurization treatment can break the sulfur cross-linking bonds in rubber powder, increasing the surface activity of the rubber powder. As some cross-linking bonds are broken, the rubber powder can swell more fully in asphalt, and under high temperature and high shear conditions, active groups are generated on the surface of desulfurized rubber

powder, facilitating chemical bonding with asphalt and improving the compatibility between rubber powder and asphalt, thus enhancing its performance in asphalt^[2].

2.2 Improving the Processability of Rubber Powder

Desulfurized rubber powder undergoes further breaking of cross-linking bonds under low-temperature and high-shear conditions in a screw extruder, which can improve its processability. After being added to asphalt, it can complete the production process at lower temperatures and in shorter times. Desulfurized rubber powder-modified asphalt can reduce the indoor trial production and processing temperature of rubber asphalt by 10–20°C, decrease energy consumption, improve workability, and expand the application range of rubber asphalt.

2.3 Improving the Performance of Rubber Powder-Modified Asphalt

Desulfurized rubber asphalt exhibits significant advantages over ordinary rubber asphalt. It demonstrates reduced viscosity and substantially improved storage stability, anti-aging performance, and low-temperature performance. Desulfurization rubber asphalt has a great improvement in low temperature ductility index, Its ductility at 5°C is more than three times that of ordinary rubber asphalt, it shows that desulfurization rubber asphalt has good low temperature performance. Desulfurization rubber asphalt has improved its elastic recovery performance, elastic recovery percentage increase, it shows that the elastic properties are improved^[3].

III. METHODS AND TECHNIQUES FOR RUBBER POWDER PRETREATMENT

During the preparation of rubber powder modified asphalt, especially high content rubber powder modified asphalt, rubber powder that has been desulfurized after pretreatment is usually used. The earlier method used for activating waste rubber involved mechanical decrosslinking. This method is to activate rubber powder molecules under certain pressure and temperature through the joint action of mechanical force and chemical additives. However, this process has high energy consumption, heavy pollution and long processing cycle. At present, the desulfurization and regeneration methods of waste rubber powder mainly include physical method, chemical method and microbial method, etc. These methods provide practical and feasible energy-saving, efficient and high-quality solutions for the pretreatment of rubber powder. It has important practical significance and engineering application value for the application of waste tire rubber powder in modified asphalt.

3.1 Thermomechanical Method

Thermomechanical method is to destroy the crosslinking network structure of rubber powder by heating, pressure and shearing, the rubber powder will undergo desulfurization reaction, typical methods are screw reactive extrusion. The waste tire rubber powder prepared by twin-screw extrusion method has high desulfurization degree and good modification effect. The rubber powder content of modified asphalt prepared by this rubber powder preparation method can reach 20% -40%, and when the rubber powder content is 30%, the comprehensive performance of the corresponding mixture is the best^[4]. In the thermomechanical method, the rubber powder is first heated to a certain temperature (usually 180-250°C) to soften the rubber particles and reduce their viscosity. High temperature helps to break the sulfur cross-linking bond, make rubber molecular chains more active and easy to rearrange. By using a twin-screw extruder or high-speed stirring equipment, high shear force is applied to the heated rubber powder. Shear force can further destroy the sulfur crosslinking network and promote the depolymerization and dispersion of rubber molecules. In order to enhance the desulfurization effect, softeners such as naphthenic oil and aromatic oil are often added in the process of thermomechanical treatment. Softeners can penetrate between rubber molecular chains, increasing molecular spacing and reducing viscosity, making shearing and dispersion easier. Common desulfurizers include disulfides such as diphenyl disulfide (DD) and dipentyl disulfide (DPDS). These desulfurizers catalyze the cracking of sulfur sulfur bonds at high temperatures, further improve the activity of rubber powder. The amount and type of desulfurizer need to be adjusted according to the specific type of rubber powder and desired modification effect.

3.2 Chemical Method

Common desulfurizers for chemical desulfurization include organic sulfides, peroxides and metal compounds. Organic sulfides such as diphenyl disulfide (DD) and dipentyl disulfide (DPDS) can catalyze the cleavage of sulfur cross-linked bonds at high temperatures, Peroxides destroy the sulfur crosslinking structure through oxidation reaction. The desulfurizer converts sulfur crosslinking bond into soluble product through chemical reaction, thus destroying the crosslinking network. This method usually requires a long reaction time, and needs to control the reaction temperature and the amount of desulfurizer, in order to avoid the degradation of rubber properties caused by excessive

desulfurization. Due to the numerous types of additives, the principles involved in the chemical method are also more complex. In order to improve the efficiency of chemical desulfurization, it is usually treated in combination with the mechanical method [5]. For example, in the process of chemical desulfurization, a mixer or extruder is used to continuously stir the rubber powder to ensure that the desulfurizer is evenly distributed and fully contacted with the rubber. The reaction conditions of chemical desulfurization (such as temperature, time and desulfurizer concentration) need to be optimized according to the specific type of rubber powder and the required modification effect. Too high temperature may lead to rubber degradation, while too low temperature cannot effectively desulfurization. Some researchers have pretreated rubber powder with sodium hypochlorite, activators, gasoline, diesel, the rubber powder content of the prepared modified asphalt can reach 30%~49% (externally added), the compatibility between asphalt and rubber powder is obviously improved, and the content of rubber powder is greatly increased^[6].

3.3 Microwave Radiation Desulfurization

Microwave radiation method uses microwave energy to break the sulfur cross-linking bond in rubber powder without destroying the carbon-carbon bond. Microwave energy can penetrate rubber particles to generate heat inside, so as to achieve rapid desulfurization [7]. The advantage of microwave radiation method lies in its selective desulfurization ability. By controlling microwave power and radiation time, it can selectively break different types of sulfur cross-linked bonds, to improve desulfurization efficiency and product quality. Microwave radiation can not only achieve internal desulfurization but also modify the surface of rubber powder. Surface-modified rubber powder has better compatibility and dispersion, better combination with base asphalt. The process parameters of microwave radiation (such as microwave power, radiation time, and sample thickness) need to be optimized according to the specific type of rubber powder and desired modification effect. Reasonable parameter setting can ensure the best desulfurization effect and product performance.

3.4 Supercritical Fluid Induced Swelling

Supercritical carbon dioxide (scCO₂) has low viscosity, high diffusivity, and good solubility, which can rapidly penetrate into rubber powder and cause swelling. This characteristic makes scCO₂ an ideal pretreatment medium. The swelling process of this method is to put rubber powder in scCO₂ environment and inject scCO₂ into the reactor through high-pressure pump. Under certain temperature and pressure conditions, scCO₂ can quickly penetrate into the interior of rubber particles, causing volume expansion and breaking down the sulfur crosslink network. Supercritical fluid pretreatment can significantly improve the compatibility between rubber powder and base asphalt. After swelling, the surface of rubber powder becomes rougher, which increases the bonding area with asphalt and improves the compatibility between them. Swelling treatment can also improve the dispersion of rubber powder in asphalt. Due to volume expansion, the interaction between rubber particles is weakened, which makes it easier to disperse evenly in asphalt and avoid agglomeration [8].

3.5 Biological Desulfurization

Biological desulfurization usually uses specific microbial strains, such as fungi, bacteria, actinomycetes. These microorganisms can secrete enzymes and selectively destroy the sulfur cross-linking bond in rubber. In order to obtain efficient desulfurization effect, it is necessary to properly cultivate microorganisms. Culture conditions include temperature, pH value, oxygen supply, etc., which directly affect the growth and metabolic activity of microorganisms. Biological desulfurization is an environmentally friendly method, which will not produce harmful by-products. In addition, less energy is consumed in the process of microbial treatment, which meets the requirements of sustainable development. Although biological desulfurization has the advantages of environmental protection, the main challenges of this method are long processing time and low efficiency. The research directions of biological methods include screening more efficient microbial strains, optimizing culture conditions and developing new bioreactor designs to improve desulfurization efficiency and economy.

IV. CONCLUSION

Rubber powder modified asphalt has significant advantages in improving road performance, reducing maintenance costs and promoting environmental protection. The compatibility between rubber powder and asphalt and the performance of the final product can be effectively improved by thermal mechanical method, chemical method, microwave radiation method, supercritical fluid induction and biological method. These pretreatment methods not only improve the dispersion and reaction of rubber powder in asphalt, but also solve the challenges of high processing temperature, energy consumption and storage stability. With the growing demand for sustainable and high-performance

paving materials, the development and optimization of efficient rubber powder pretreatment technology will be the key to give full play to the potential of rubber powder modified asphalt in modern road construction.

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