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The State-of-the-Art Review on Road Harmless Utilization Technology of Phosphogypsum

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Abstract. The "Guiding Opinions on the Comprehensive Utilization of Bulk Solid Waste during the 14th Five-Year Plan" issued by the Ministry of Ecology and Environment in 2021 pointed out that by 2021, China's cumulative bulk solid waste stockpiles are about 60 billion tons, and the annual new stockpiles are nearly 3 billion. At the same time, there is a problem of low solid waste utilization rate, occupying a large amount of land resources, and a large hidden danger to the ecological environment. In order to further improve the utilization of solid waste, reduce the cost of road construction, and reduce the damage and impact of solid waste accumulation on the environment. This paper analyzes phosphogypsum impaction of the incorporation of various solid wastes on asphalt penetration, softening point, ductility and other properties, as well as the impact on the high temperature stability, low temperature crack resistance and water stability of asphalt mixtures, and the summarize and evaluate the microscopic modification mechanism and other aspects. At present, there is a relatively lack of research on the reuse of some solid wastes in asphalt in China. This review can provide reference and reference for judging a variety of solid wastes as asphalt modifiers, promote the green reuse of solid wastes, and reduce the construction of asphalt pavements.

Keywords. Solid waste, asphalt binder, economic and social effects, recycling, mechanism, review

1. Introduction

With economic development and urbanization, China's solid waste generation is increasing year on year. As of 2015, China produced 3.2 billion t of general industrial solid waste, an increase of 14.59 million t compared to the same period in 2014. Waste reuse is becoming a fundamental policy in waste management systems around the world [1]. The accumulation of large amounts of solid waste can cause heavy metals in the waste, such as lead, cadmium and chromium, to leach out and enter the soil, surface water and groundwater, which can be harmful to human health and the environment [2].

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Solid waste can be used for road construction when certain technologies are applied, solving the problem of waste disposal and alleviating the shortage of raw materials for construction. Asphalt pavement is the main form of pavement structure for highways in China. Almost all of the highways built and under construction use asphalt concrete pavement, the vast number of raw materials required for road construction is a huge drain on limited natural resources [3].

Solid waste can therefore be used for road construction after certain technical treatment, which can solve the problem of waste disposal, protect the environment and also alleviate the shortage of raw material supply for construction.

2. Phosphogypsum

Phosphogypsum is mainly produced as a result of solid waste discharged from the industrial production of phosphate fertilizers, phosphoric acid and other products. Its color is generally light grey and its shape is generally a powdery solid. Its main component is calcium sulphate, but it is subject to some process influences. It may also contain some soluble and insoluble impurities [4], the chemical composition is shown in the table 1.

Table 1. Chemical composition of Phosphogypsum [5].

Chemical composition (wt%)	Phosphogypsum
CaO	30
SiO2	1
SO3	45
Al2O3	1
F	0.6
Fe2O3	0.01
Na2O	0.15
K2O	0.003
P2O5t	1.23
Loss on ignition	21

Currently, the main sources of phosphogypsum by-products in China are wet phosphoric acid for the production of calcium magnesium phosphate fertilizer and monoammonium phosphate products, wet phosphoric acid for the production of feed-grade calcium hydrogen phosphate, calcium dihydrogen phosphate and phosphate, and wet production of industrial phosphoric acid, which is produced as a by-product of the industrial phosphate process after purification. At the same time, phosphogypsum contains free acid. Long-term piling will pollute groundwater sources, seriously damage groundwater quality, affecting the lives of the surrounding people and causing environmental pollution; Finally, long-term piling will reduce the amount of phosphogypsum sand light per unit area. It increases the cost of land occupation and

limits the economic development of enterprises and the local area. At present, domestic industrial by-product phosphogypsum is mainly used for the production of sulphuric acid co-production cement, building materials, cement retarder, ammonium sulphate production, crop fertilizer and soil conditioner [6]. However, the utilization rate of by-product phosphogypsum cannot be significantly increased due to the current immature treatment technology and high treatment costs. In order to understand the problem of excess industrial by-product phosphogypsum and to reduce the cost of asphalt, it is necessary to blend industrial by-product phosphogypsum into asphalt. This section will outline the effect of the industrial by-product phosphogypsum on the properties of bitumen and its blends.

3. Characteristics of Phosphogypsum on the Technical Performance of Asphalt

In order to study the influence characteristics of phosphogypsum asphalt, some scholars added different amounts of phosphogypsum to asphalt to study the results of phosphogypsum filler on the improvement of asphalt pavement performance. The results show that adding phosphogypsum to asphalt improves its rheological properties at high temperatures without adversely affecting low temperature performance, while increasing viscosity and softening point and reducing permeation levels [7]. Therefore, Diao Mengna concluded that the addition of phosphogypsum reduced the sensitivity of the bitumen to temperature while hardening the bitumen and could not improve the low temperature performance of the bitumen. Qiu et al investigated the appropriate ratio of bitumen and phosphogypsum powder through performance tests and found that the ratio of the two affected properties such as tensile strength and spent life [8]. Cuadri et al investigated the potential utilisation of phosphogypsum as a modifier for incorporation into bitumen [9]. The FTIR testing results are shown in the figure 1.

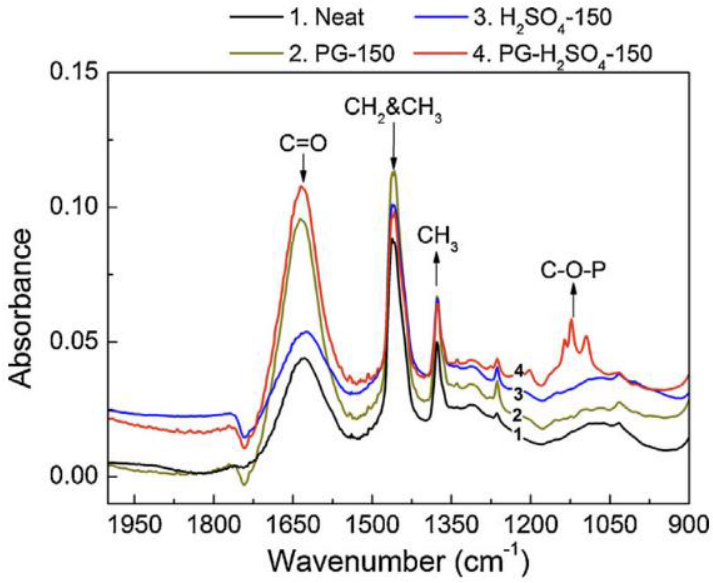

Figure 1. FTIR spectra, from 2000 to 900 cm^{-1}, for the neat bitumen and selected modified binders [9].

The results of this study showed a significant improvement in the rheological properties of the bitumen. It was observed that this improvement was more pronounced at higher temperatures compared to lower mixing temperatures. Through research it was found that as the phosphogypsum powder content increased, the softening point of phosphogypsum asphalt first increased and then stabilised, while the permeability kept decreasing steadily, which are shown in figure 2. Using infrared spectroscopy tests, Xiao et al found that phosphogypsum modified bitumen is a physical co-blending modification without chemical reaction. It is used to improve the stability of the bitumen by the formation of a mesh structure in the bitumen by phosphogypsum [9]. The filler only improves the activation of the surface, changing it from hydrophilic and lipophilic to lipophilic and hydrophobic, enhancing the surface physical adsorption properties of the filler and improving compatibility with the bitumen. As a result, the high temperature stability and temperature sensitivity of the bitumen is improved. However, phosphogypsum is rigid and its addition reduces the toughness of the bitumen, and the inorganic rigid particles do not produce large elongation and deformation. Under the action of tensile force, the interface between the filler and the asphalt body debond, forming holes and concentrating stresses, which are prone to fracture. Therefore, phosphogypsum filler cannot change the low temperature crack resistance of bitumen.

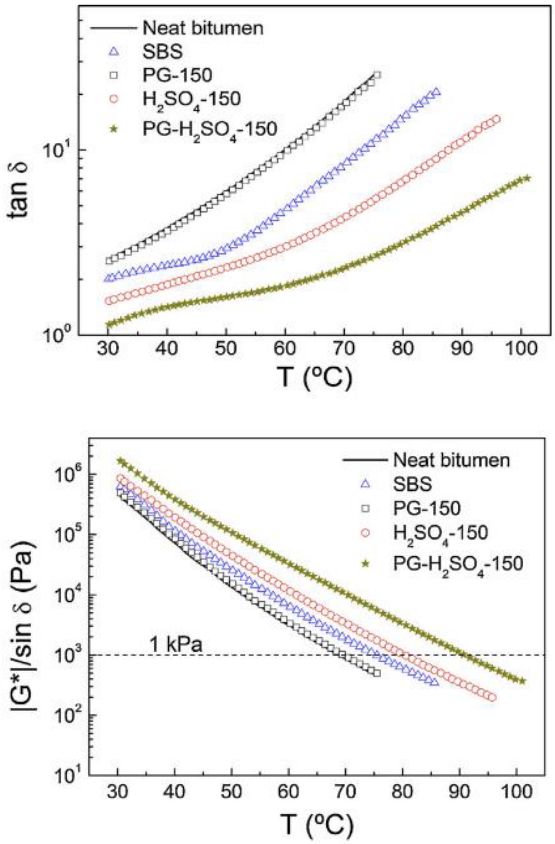

Figure 2. The influence of phosphogypsum on the rheological properties of asphalt binder.

4. Effect of Phosphogypsum on the Technical Properties of Asphalt Mixes

According to the research of Cuadri et al, the incorporation of phosphogypsum into asphalt mixes within a reasonable range can significantly improve the high temperature rutting resistance and Marshall performance of asphalt mixes [10]. Amrani et al carried out rutting tests and showed that the dynamic stability of phosphogypsum asphalt mixes would be significantly improved, a phenomenon that suggests that phosphogypsum incorporation can improve the high temperature stability of asphalt mixes [5]. Since phosphogypsum contains some calcium sulphate whiskers, Cuadri et al (2014) found that the high temperature performance of the asphalt mixture was not as significant as that of conventional polymer modified asphalt when the calcium sulphate whiskers were mixed into the asphalt mixture alone. Abreu et al carried out a small beam bending test on asphalt mixes. The results showed that the calcium sulphate in phosphogypsum increased the low temperature crack resistance of the asphalt mix within the optimum dosing range [11]. Once the optimum admixture was exceeded, the low temperature stability of the asphalt was reduced. These conclusions were also reached in a study by Cuadri et al (2014). However, Abreu et al analysed that the incorporation of calcium sulphate whiskers enhanced the interfacial bonding effect between the asphalt and the aggregate, requiring greater interfacial energy for water erosion and stripping [11]. On the other hand, calcium sulphate whiskers not only fill some of the voids in the asphalt mixture, but also form a three-dimensional network cross-linking effect in the asphalt mixture, which improves the overall strength and durability of the mixture to a certain extent. As phosphogypsum contains a certain amount of calcium sulphate, phosphogypsum can improve the water stability of asphalt mixes, but more research is needed for related conclusions.

5. Social Effects

Since the 18th Party Congress, China has incorporated comprehensive utilization of resources into the overall layout of ecological civilization construction, continuously improved regulations and policies, strengthened scientific and technological support, and improved standards and regulations, which has promoted the development and growth of the comprehensive utilization of resources industry. Positive progress has been made on various fronts. on 18 March 2021, the 17th meeting of the Standing Committee of the 13th National People's Congress amended the Law of the People's Republic of China on Solid Waste Pollution of the Environment on 29 April 2020, and the National Development and Reform Commission and other 10 departments jointly issued the "14th Five-Year Plan" guidance on the comprehensive utilization of bulk solid waste", further proposed to improve the level of comprehensive utilization of bulk solid waste, an overall increase in resource utilization, and promote the construction of ecological civilization to promote high-quality development, although in recent years China's solid waste utilization rate has made some progress, but compared with developed countries abroad there is still a gap, especially "to protect the ecological environment is to protect productivity, and to improve the ecological environment is to develop productivity". Everyone is closely related to the ecological environment around them.

Once solid waste can be mixed into asphalt, asphalt mortar and asphalt mix, it can effectively improve the environmental pollution and damage caused by the

accumulation of large amounts of solid waste, which affects the health of residents, which is in line with our country's "good ecological environment is the most universal well-being of people's livelihood" and "economic development is for people's livelihood, while protecting the ecological environment is also for people's livelihood, which can promote the formation of a modern construction of harmonious development of man and nature A new pattern, it is one of the important aspects of safeguarding people's health and safety and the green development of society as a whole, a positive response to people's growing need for a beautiful ecological environment, and can yield huge social benefits.

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