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Research Progress of Epoxy Asphalt Material for Roads

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Abstract: Asphalt is a semi-solid or solid mixture formed by hydrocarbons and non-metallic elements. It is widely applied in the fields of building waterproofing and road paving. Asphalt is a low noise, durable, and renewable pavement material. However, asphalt materials have some shortcomings such as liquefying at high temperatures and brittleness at low temperatures, which are less adaptable to different environments. Therefore, people have gradually shifted their focus to asphalt modification. This paper presents an in-depth analysis and research on the composition, structure, and performance of epoxy asphalt materials for roads, so that this material can be widely used.

Keywords: Epoxy asphalt material for roads; Asphaltene; Toughness modification

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1. Introduction

Due to its excellent performance and long durability, epoxy asphalt is widely used in steel bridge deck pavement. Bridge pavement is a relatively common bridge structure in bridge engineering. It will be affected in different ways when vehicles pass through it, and rutting will also occur; shrinkage cracks and fatigue cracks will appear at lower temperatures. Pavement materials can be detached from the road surface due to moisture, resulting in problems such as looseness and potholes. Therefore, it is of great significance to systematically analyze and study the high temperature and low temperature crack resistance, water stability, and other aspects of asphalt materials.

2. Research status of epoxy asphalt materials for road

At present, epoxy asphalt manufactured by Chem Co Systems, an American company and TAF, a Japanese company is the most used in the deck layer of steel bridges in our country, among which the products of Chem Co Systems dominate, and its consumption accounts for 80% of the steel bridge decks in our country. In terms of epoxy asphalt's compressive strength, flexural modulus, Marshall stability, dynamic stability, and solidification modulus, TAF is better than Chem Co Systems. However, at 15 °C, 10Hz, and 600 microns, TAF's epoxy pitch has better four-point bending fatigue than Chem Co Systems. Besides, TAF's epoxy-based asphalt mixture also has many advantages, such as simple construction management, short maintenance period, little to no pavement foaming, etc. In addition, the epoxy asphalt cementitious material of TAF has a high modulus, which allows the cementitious material and the steel sheet to bond more strongly, which reduces the strain of the pavement material [1].

Professor Huang of Southeast University, an academician of the Chinese Academy of Engineering, has made great contributions to the development of our country's epoxy asphalt industry. The Second

Nanjing Yangtze River Bridge led by Huang used epoxy-based asphalt concrete for the first time in 2001 and achieved good results after 15 years. Therefore, they took the lead in the development of epoxy-based asphalt concrete in China.

3. Composition and structure of epoxy asphalt materials for roads

Epoxy asphalt is mainly made of asphalt, epoxy resin, and curing agent. During the blending process, due to the interaction between epoxy resin and curing agent, the asphalt forms a cross-linked three-dimensional network structure. Therefore, at high temperatures, the asphalt will not deform due to thermal expansion; and at low temperatures, its crack resistance is significantly enhanced, which is higher than that of ordinary asphalt. The results show that the microstructure and properties of epoxy asphalt not only depend on the ratio of epoxy resin and asphalt, but also the curing and composition of asphalt and epoxy resin [2].

3.1. Effect of asphalt composition on epoxy asphalt

The actual composition of epoxy asphalt is relatively complex. It can be divided into soft mineral tar and asphaltene according to the degree of solubility. Mineral tar can be separated into three components through chromatography – saturated, aromatic, and colloid. The different composition and polarity of asphalt molecules will produce different effects with epoxy resin, thus resulting in large differences in structure and properties. Asphaltene is the most easily separated component in asphalt, and it is also the main component in asphalt. It has a great influence on the viscosity and hardness of asphalt. Saturated and aromatic components in loose asphalt are easily absorbed by polymer chains, causing swelling of the asphalt, which also has a certain impact on the properties of epoxy resin [3].

There is a big difference in the interaction between mineral tar and asphaltenes with epoxy resins. Studies have been done on phase separation, viscosity, and mechanical properties of epoxy resin compositions with different oil contents. It was found that if the proportion of asphaltene decreased, the viscosity of epoxy asphalt increased, and the damping performance and mechanical properties will be improved [4]. In the composition of epoxy resin, the higher the content of asphaltene, the phase separation size of the asphalt microdomains in the epoxy asphalt gradually increases, and there will be uneven distribution. Some scholars separated asphaltene and mineral tar from asphalt and blended them with epoxy resin respectively and conducted in-depth research on the influence of asphaltene and mineral tar on the microstructure and properties of epoxy asphalt [5]. It was found that the viscosity of the epoxy resin increased as the asphaltene content increased. In a study done by Min *et al*., a small amount (1%) of asphaltene microdomains were distributed evenly. The asphaltene micro-domain gradually increased with the increase of asphaltene content and caused a non-uniform distribution state. Asphaltenes increased the storage modulus of epoxy resins while they are in the rubbery state. With the same amount of bitumen, the epoxy resin system had a lower viscosity. The glass transition degree of epoxy asphalt gradually increased when the tar content increased. When the tar content does not exceed 50%, the mechanical properties of epoxy mineral tar are significantly better than those of epoxy asphalt [6].

In engineering practice, in order to improve the performance of epoxy asphalt, it is usually necessary to modify the base asphalt. This practice is more common in thermoplastic elastomers and thermoplastic resins. Poly(styrene-butadiene-styrene) (SBS) is a styrenic thermoplastic elastomer, which belongs to the triblock copolymer of butadiene, styrene-styrene triblock, and is currently the most widely used modifier. Because polybutadiene is highly compatible with asphalt, the light components in SBS and asphalt are fully swollen, so that they are evenly dispersed in the base asphalt. SBS modified asphalt can be added to epoxy resin to produce epoxy asphalt. With epoxy resin as the main raw material, SBS is used to modify the asphalt to produce a new type of epoxy asphalt. Studies have shown that the mechanical properties of the SBS modified asphalt-epoxy resin composite is the best when the polystyrene content is 30%.

3.2. Effect of epoxy resin and its curing agent on epoxy asphalt

Epoxy resin, curing agent, and other toughening and compatibilizing additives together form an epoxy resin system. The curing process has been heavily studied due to its importance. Epoxy resin is a type of low molecular weight polymer, and its molecular structure is composed of two or more epoxy groups and aliphatic, alicyclic, or aromatic compounds. The presence of the epoxy group in the epoxy resin allows the formation of an insoluble and infusible cross-linked polymer with a variety of curing agents. There are a few types of epoxy resin: glycidyl ether, glycidyl amine, alicyclic epoxy, and vinyl epoxy, all with different structural characteristics. When applying these products, the proportion of the glycidyl ether is the largest while the cost performance of bisphenol A epoxy resin is relatively high. Therefore, bisphenol A epoxy matrix is also mainly used in the preparation of epoxy matrix at present.

There are a few types of curing agents, such as polythiols, organic acids, aliphatic or cycloaliphatic amines, etc. Epoxy resin glue can be roughly divided into four types according to the reaction temperature: (1) polythiol curing agent is a low-temperature curing agent; (2) aliphatic amine, alicyclic amine, low molecular weight polyamide etc. are all room temperature curing agents; (3) some of them are medium temperature curing agent systems such as alicyclic polyamines, imidazoles, and resins; (4) acid anhydrides, aromatic polyamines, phenolic resins, etc. are all high temperature resistant curing agent system.

After mixing the epoxy resin and the curing agent, the curing time of the initial mixture should be in line with the requirements of asphalt concrete mixing, transportation, paving, and rolling. In addition, the curing agent should not only work in high temperatures, but also at room temperature. The requirements of epoxy asphalt should also be considered when selecting the curing agent. In the 1960s, some scholars used diethylenetriamine and phthalic anhydride as epoxy resin curing agents, and tar as a solvent to synthesize a new type of epoxy resin asphalt material [7]. However, the compatibility of the curing agent and tar has great influence on the properties of the epoxy resin. Since then, other epoxy asphalt curing systems have been developed. Relevant scholars have proposed an epoxy asphalt material for road Bridges, which includes two parts: one is epoxy resin, and the other is modified asphalt and curing agent containing carboxyl and anhydride groups [8]. Aliphatic dibasic acid has also been used as a curing agent with maleic anhydride as the modifier to produce high-performance epoxy asphalt [9]. On some occasions, in order improve the comprehensive performance of epoxy asphalt, it is necessary to add some composite curing agent. For example, an epoxy asphalt composite material can be prepared using sebacic acid, modified tung oil anhydride, and methyl tetrahydrophthalic anhydride as curing agents, an. This method shortens the induction period of the curing reaction and improves the tensile strength, surface hardness' and glass transition temperature of the epoxy bitumen.

3.3. Structure of modified epoxy asphalt

As a new type of modified material, epoxy resin has been applied on long-span bridge decks because of its excellent performance. However, since it is a multi-component composite material, it is difficult to achieve a synergistic effect only by simple doping. Besides, due to the difference in polarity and density, it is difficult to achieve uniform dispersion during the curing process, and long-term storage will cause peeling. In addition, because its main substance is rich in benzene rings, it has excellent mechanical properties such as compression resistance and wear resistance, but its plasticity is insufficient. Large deformation of the steel bridge deck damages the asphalt layer. Fatigue and other factors cause cracks that are difficult to repair. Therefore, a set of studies on improving the toughness and compatibility of epoxy asphalt has also been carried out, in hopes of developing epoxy asphalt materials that can meet the actual engineering needs.

3.4. Toughening modification

The crack resistance of epoxy asphalt is not ideal due to the high degree of cross-linking and brittleness of epoxy rubber. Therefore, it must be toughened to improve its performance. Among them, rubber elastomers, thermoplastic resins, nanoparticles, and polymers with low glass transition rates are commonly used toughening agents. For example: some scholars mixed terminal carboxylated nitrile rubber with epoxy asphalt to obtain a cold-mixed epoxy asphalt with high toughening properties [10]. Ethylene glycol-polyvinyl acid copolymer (EVA) can be used to toughen the epoxy resin. Studies showed that good comprehensive properties can be achieved when the mass content of EVA is 1.9%. The tensile elongation and tensile strength increased by about 7.8% and 30%, respectively with added EVA compared to regular asphalt epoxy. Some scholars chose natural nano-clay (attapulgite) as a toughening agent and it was found that nano-clay can greatly improve the tensile strength, various moduli, and viscosity, bonding strength, and the thermal stability of epoxy asphalt [11]. Polymethyl methacrylate have also been used as the core and polybutadiene as the shell to mix core-shell nanoparticles with epoxy resin and asphalt to obtain a new type of nanoparticle with high specific surface area of the new epoxy asphalt composite system. The purpose of the project was to achieve homogenization of asphalt micro-regions through adding nanoparticles; at the same time, the polybutadiene in the nanoparticles also has the effect of toughening and modifying. The experiment found that with nanoparticles, the tensile strength increased by 29%, the elongation at break increased by 60%, and the toughness increased by 200% after adding 1% nanoparticles. However, in reality, due to the addition of some toughening modifiers, the viscosity of this system will often increase, which will have a certain impact on the structure. Thus, some small molecule plasticizers can be added to meet the needs of the building. Small molecule plasticizers like phthalates have the effect of reducing viscosity and toughening, but it tends to leak, which will negatively affect the properties of materials and the environment. Compared to small-molecule plasticizers, polymers with flexible chains like polyethylene glycol can reduce the viscosity of the system and the degree of cross-linking of the epoxy resin, thereby achieving a toughening effect, but it does not transfer to the surface, leading to the instability of material properties [12].

4. Conclusion

Generally speaking, although the performance of epoxy asphalt for roads have been greatly improved through modifications and optimizations, there is no systematic research on the internal between its mesostructure and performance. In the construction of epoxy asphalt, due to factors such as construction temperature, system viscosity, and construction time, various requirements are put forward for the selection of curing agent, viscosity control, and optimization of curing time. Therefore, the development of a low viscosity epoxy asphalt with high operability and toughness is the main issue. In recent years, in order to improve the performance of the project, people a new type of water-based epoxy asphalt has also been developed. In addition, epoxy-based asphalt is a thermosetting substance and cannot be reused. Therefore, dynamic bonds are added to the epoxy resin matrix so that the matrix can be regenerated.

Disclosure statement

The authors declare no conflict of interest.

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