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Review

Development of methods improving storage stability of bitumen modified with ground tire rubber: A review

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ABSTRACT

The following paper presents an overview of methods for improving the storage stability at high temperature of rubber modified bitumen. The storage stability of the rubber modified bitumen can be improved by using a various types of modifiers that form the bonds between the components of these binders. The increase in stability can also be achieved by using crumb rubber surface-activated by furaldehyde or ground tire rubber (GTR) treated by gamma irradiation or modified by devulcanization process. The storage stability of rubber modified bitumen can be also improved by preparing compositions obtained from GTR and other components leading to a reduction in density as compared to unmodified GTR. unmodified GTR.

Contents

1. Introduction

The amount of polymer wastes is increasing every year. Most of them are obtained from postconsumer tires [1], which are a serious environmental problem [2–4]. Development of research on improving methods of recovery and recycling and regulations implementing [5–15] the principle of extended producer responsibility in the field of life tires led to solutions that enable the transformation of rubber waste into energy or new polymer products. The progress made in recent years mean that ground tire rubber (GTR) came to be seen not only as a cheap filler, but primarily as a source of valuable raw materials [6–7, 16–17]. Ground tire rubber is commonly used as a filler in thermosets, thermoplastics and elastomers (e.g. virgin rubber or polyurethanes), [18–20] or as a modifier of concrete [21–24] and also asphalt [25–29] to improve the properties of these materials [30].

Bitumen is a viscoelastic material which has good mechanical and rheological properties preferred for road surface. However, with the increasing number of vehicles on the road, there is a need to improve the properties of the asphalts, for example, strength, fatigue, rutting, resistance to aging, low temperature cracking. In order to improve the properties of asphalt the polymers are added into the asphalt composition [31–33]. From the economical point of view, recycled polymers are more attractive. Much of the research in the field of asphalts modified with polymer wastes relates to the use of ground rubber from waste tires, as a modifier of their properties [34–35]. Rubber-modified bitumen, compared to the unmodified asphalt is characterized by improved mechanical properties, in particular increased flexibility, abrasion

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resistance, resistance to rutting and cracking resistance at low temperatures and ability to reduce the noise during contact of tires with the ground [36].

However, polymers-modified asphalt has a low resistance to aging [37]. Due to weak physical interactions and no chemical interactions between the asphalt and polymer modifiers, polymer-modified bitumen has very poor storage stability at high temperature (140–180 °C) [38].

The modifier can be separated from the asphalt and depending on the density of modifier molecule thereof may fall to the bottom of storage tanks or rise to the surface. As the consequence, decomposition of the polymer-asphalt binder may occur [37]. This phenomenon is causing the loss of bituminous binders properties of modified asphalt and can cause a failure of the system to transport asphalt by pipelines. Therefore bitumen modified by incompatible polymers have to be constantly mixed.

The following topics are discussed in this article: interactions occurring in the rubber modified bitumen, stability test methods of rubber modified bitumen and methods of modifying bitumen with rubber in the direction of improving their stability at high temperature during storage.

2. Rubber modified bitumen obtained from ground tire rubber (GTR)

2.1. Properties of rubber modified bitumen derived from GTR

Historically speaking, the use of rubber granulate as an asphalt modifier for paving roads, started in the 1840s. In those days, it was made the first experiment involving natural rubber and asphalt. Attempts of modifications were carried out to take advantage of the elastic properties of natural rubber to get more wear-resistant asphalt. Since 1960, shredded postconsumer tires are also recycled for use as a component of asphalt [8]. The research led to the division of modification methods into wet and dry processes. The wet process comprises preparing a liquid rubber-modified bitumen by mixing asphalt and rubber granules for at least 45 min at a temperature of 180–210 °C. The next stage is a maturation of rubber-modified bitumen for 3 h at 180 °C without stirring [10]. The obtained mixture is combined with mineral aggregate. Dry way is the introduction of granulated rubber for mineral aggregate before entering the bitumen, and then mixing all the ingredients at 163 °C [39–40]. Favorable properties of road pavements are obtained using wet method.

Charles McDonald was the first person who developed a method of modifying an asphalt rubber granules by wet process. He proved that rubber modified bitumen is characterized by the favorable characteristics from both the base materials. At the same time, two Swedish companies replaced part of the mineral aggregates in asphalt mixtures by granulated rubber (dry process), thereby obtaining an asphalt mix with increased resistance to the effects of the snow chains [8,41].

The GTR modified asphalt is under investigation by many researchers, and are widely used by manufacturers. This is because, the addition of GTR to asphalt contributes not only to solve the problem of utilization of waste tires, but also affects the improvement of the mechanical properties of asphalt, and consequently the durability of road surfaces [35]. The rubber-modified bitumen, compared to the unmodified binders are characterized by increased fatigue strength, resistance to rutting and low-temperature cracking. They also are characterized by higher values of the viscosity and the softening point and a lower penetration values. The advantage of asphalt concrete obtained from the rubber-modified bitumen is also reduction of a noise resulting from the contact of the tire with the ground. It has been shown that the adhesion of the vehicle wheels to the surface of the rubber modified asphalt is improved compared to unmodified asphalt. This shortens braking distances of vehicles, and thus contributes to increased road safety [29,42–45].

2.2. Interactions occurring in rubber modified bitumen obtained from GTR

Despite the development of research in the field of asphalts modified by ground tire rubber, interactions occurring between ground tire rubber and asphalt are not fully understood. According to current knowledge, the physical interactions has a major effect on the properties of the rubber modified bitumen, but chemical interactions are not significant. Understanding the interactions between asphalt and granulated rubber is extremely important not only in the course of modification, but also during processing, storage and use of binder [10,46].

Two phenomena are important when considering the properties of asphalt binders modified by ground rubber:

- Absorption of light fractions of asphalt (aromatic oils) by ground rubber;
- Decomposition of ground rubber in asphalt.

Absorption of light fractions of asphalt by rubber granulate may occur during the addition of ground rubber to asphalt heated. It causes swelling of the ground rubber and expands up to three times compared to the original volume. This in turn decreases the distance between the grains of the rubber granulate distributed in liquid asphalt, which results in even tenfold increase of viscosity [8,10].

Decomposition of rubber grains in asphalt occurs when the temperature of the asphalt modification is too high or the mixing time during the modification is too long.

Then, two the processes take place, such as depolymerization and devulcanization, followed by partial disintegration and dissolution of ground rubber in liquid asphalt, which reduces the viscosity of the rubber modified bitumen [8,10].

2.3. Lack of stability of rubber modified bitumen during storage at high temperature

The instability of the rubber modified bitumen at high temperature creates a serious problem in its application. The compositional heterogeneity of the rubber modified bitumen, as well as the difference in density between bitumen and rubber granulate are the reason that the rubber granulate originally evenly distributed in the rubber modified bitumen, tends to fall to the bottom of the tanks during storage [35,38]. The phase separation phenomenon of the rubber modified bitumen describes Stokes' law, according to which, the settling velocity of rubber grains to the bottom of the tank is as follows:

$$\vartheta_t = 2\alpha^2 \rho g / 9\eta \qquad (1)$$

where:

- ϑ_t - the settling velocity of the distributed rubber granulate [m/s];
- α - the radius of the distributed rubber granules [m];
- η - the dynamic viscosity of liquid [Pa·s];
- $\Delta\rho$ - the density difference between phases (rubber granulate and bitumen) [kg/m^3];
- g - gravitational acceleration [m/s^2].

According to Eq. (1), it can be concluded that stable rubber modified bitumen can be obtained by:

- decreasing the particles size of rubber granulate;
- decreasing the density difference between rubber granulate and bitumen;
- increasing the viscosity of bitumen [10].

The instability of the rubber-modified bitumen causes difficulties in its application. When the liquid rubber-modified bitumen is stored at high temperature (about 180 °C), the rubber grains falling on the