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Combustion properties of saturates, aromatics, resins, and asphaltenes in asphalt binder

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HIGHLIGHTS

- Thermal properties of four components separated from asphalt binder are discussed.
- Thermal decomposition temperature range of four components show gradient distribution.
- CO_2 and H_2O are the most important products during the combustion of each component.
- Charring integrity of combustion residue becomes better from saturates to asphaltenes.
- Combustion properties of asphalt binder are further understood at the component level.

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ABSTRACT

To further understand combustion properties of asphalt binder at the component level, four components such as saturates, aromatics, resins, and asphaltenes (SARA) were first separated from asphalt binder. Then thermogravimetry-Fourier transform infrared spectroscopy (TG-FTIR) was used to study combustion properties and released volatiles of each SARA fraction, and microscopic morphology characteristics of combustion residues were observed. The results indicate that the contents of aromatics and resins are higher than those of saturates and asphaltenes. The combustion process of each SARA fraction contains two main mass loss stages. Also, there are obvious differences among SARA fractions in combustion temperature range, maximum thermal mass loss temperature, mass loss percentage and mass loss rate in each combustion stage. The thermal properties becomes more and more stable from saturates to asphaltenes. The main combustion temperature ranges of SARA fractions show obvious gradient distribution characteristics from low to high temperature. Additionally, the volatiles released from each SARA fraction are composed of different kinds of hydrocarbon compounds and gaseous products. There are larger differences in volatile constituents in different combustion stages of each SARA fraction. However, the carbon dioxide and water are always two main products in different combustion stages of each SARA fraction. Finally, the charring layer integrity after combustion of SARA fractions becomes better and better from saturates to asphaltenes. It is believed that the combustion properties of asphalt binder are further understood at the component level.

1. Introduction

Asphalt binder, as a building material, has been used in such aspects as building waterproof, pavement binder, pipeline antirust agent and so on [1]. Most asphalt is utilized as a binder in pavement engineering [2]. Asphalt pavement is widely applied in road tunnels due to its advantages, for example, driving comfort, low noise, good skid resistance, short construction period, and maintenance convenience [3]. However, when a fire occurs due to traffic accidents, the temperature in tunnel is up to 1000 °C within a very short time [3]. It is believed that the burning behavior of asphalt pavement plays a important role in a tunnel fire, releasing a lot of smoke and heat [4]. This is because that asphalt binder is composed of hydrocarbons and nonhydrocarbons which are flammable at about 300 °C [4].

During the combustion of asphalt binder, a great deal of toxic fume is released, including inorganic gas, organic volatile compounds, suspended particles, and condensational fog after volatilization [5]. These gaseous products are more harmful to people than the fire itself [6]. It was reported that 85% of deaths in a

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fire were because of inhaling toxic smoke [7]. This leads to an fearful fire hazard, hindering the trapped personnel to escape, bringing great difficulty to fire rescue work of firefighters, which may cause significant economic losses and casualties in a tunnel fire. Therefore, it is necessary to further study the combustion properties of asphalt binder at the component level.

Recently, many researchers have focused on the thermal decomposition of asphalt binder at high temperature. Zhang et al. [8] investigated the pyrolysis, combustion and gasification behaviors of deoiled asphalt. The mass loss process of asphalt binder were divided into three stages. The asphalt pyrolysis was also studied using gas chromatography–mass spectrometer combined technique in the presence and absence of water [9]. The results indicated that the pyrolysis was the first step of asphalt conversion process. Different types of asphalt binder were analyzed using TG and limiting oxygen index (LOI) test [10]. The results showed that the ignitability and smoke emission of asphalt binder were related with the composition of SARA fractions.

Xu et al. [11] analyzed the thermal decomposition characteristics of asphalt binder, and pointed out that the combustion process of asphalt binder was multistage. Zhang et al. [12] evaluated the effects of mixed decabrombromodiphenyl ethane and antimony trioxide on the flame retardancy of epoxy modified asphalt binder using horizontal burning and LOI tests. Additionally, some researchers have also studied the effects of single or composite flame retardants on the combustion of asphalt binder, and found that the composite flame retardants had a significant impact on the combustion performance of asphalt binder [13]. Varfolomeev et al. [14] analyzed the SARA fractions of five different crude oils, and investigated their combustion behavior and kinetics using combustion calorimetry and thermogravimetry techniques, respectively. The thermal decomposition of heavy crude oil and its SARA fractions using differential scanning calorimetry (DSC) and thermogravimetry (TGA) methods were also reported [15].

So far, the burning problem of asphalt pavement in tunnel fire has attracted more and more attention [16]. Puente et al. [17] evaluated the contribution of two different pavements to fire growth and the toxic gases using cone calorimeter and FTIR. Bonati et al. [18] used the cone calorimeter to study thermal properties and combustion behavior of different kinds of asphalt mixtures at different radiant heat fluxes. Xu et al. [19] evaluated the effects of flame retardant on combustion properties of asphalt binder using horizontal burning, LOI and direct combustion tests.

These research results provided important references for the asphalt application in tunnel pavement. However, asphalt binder contains numerous complex compositions and their paralleling and consecutive reactions occur during their combustion. As a result, the combustion reaction of asphalt binder is extremely complicated [20]. Current studies on combustion properties of asphalt binder were based on thermal analysis experiments, and asphalt binder was usually regarded as a single-component entirety material. In fact, asphalt binder, as a kind of multi-component polymeric materials, is composed of hydrocarbons and heteroatoms. Four generic SARA fractions were usually separated from asphalt binder [21].

Also, this separation approach of SARA fractions was adopted to analyze chemical compositions of heavy crude oils derived from different crude sources [22]. There are obvious differences in physicochemical properties among SARA fractions, and which have significant effects on combustion properties of asphalt binder [23]. Further, few studies on combustion behaviors of asphalt binder were carried out based on the thermal decomposition of SARA fractions, and the gradient distribution characteristics of SARA fractions were seldom discussed. Therefore, it is difficult to reveal the combustion essence of asphalt binder without understanding the thermal decomposition performance of each SARA fraction.

In our previous work [24], we have discussed physicochemical and pyrolysis properties of SARA fractions using TG and FTIR, respectively. However, combustion behaviors of each SARA fraction in asphalt binder were not investigated using the TG-FTIR combined technique, respectively. We did not involve in the combustion performance of each SARA fraction in asphalt binder, nor did we identify the constituents of released volatiles during the combustion of each SARA fraction. The objective of this study is to further understand combustion properties of asphalt binder and identify the constituents of released volatiles from a new perspective of combustion properties of each SARA fraction. This is conductive to provide a profound insight into combustion mechanism of asphalt binder when exposed to fire.

In this study, SARA fractions were first separated from high-viscosity asphalt binder, and then the combustion properties of each SARA fraction and its released volatiles were investigated using TG-FTIR combined technique. The thermal stability of each SARA fraction was discussed, respectively, and their temperature gradient distribution characteristics in different combustion stages were analyzed. Furthermore, gaseous volatile constituents released from each SARA fraction in their different combustion stages were identified, respectively. Finally, microscopic morphology characteristics of combustion residues of each SARA fraction were observed using the field emission scanning electron microscopy (FESEM) to further understand the combustion mechanism of SARA fractions and asphalt binder. It is believed that combustion properties of asphalt binder were better understood at the component level, which provides a basis to develop flame retardants for asphalt binder.

2. Experimental

2.1. Materials

High-viscosity asphalt binder was obtained from SK Corp., Republic of Korea. The basic physical properties of asphalt binder was tested, and test results are presented in Table 1.

2.2. Method

2.2.1. SARA fractions separation

In this study, four SARA fractions were separated from high-viscosity asphalt binder according to asphalt chemical component test method (T0618) in China Standard Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering (JTG E20-211), which is similar to ASTM D4124-09. The principle of separation method is based on the different SARA fractions to dissolve in different solvents and the different adsorption capacity of alumina to different SARA fractions. The experimental flow chart is shown in Fig. 1. The contents and appearances of each SARA fraction were given in Table 2.

Table 1
Basic physical properties of high-viscosity asphalt binder.

Physical properties	Standard	Test results
Penetration (25 °C, 0.1 mm)	ASTM D5-06	54.2
Softening point (°C)	ASTM D36-06	87.2
Ductility (5 °C, cm)	ASTM D113-07	35.1
Brookfield viscosity(135 °C, Pa·s)	ASTM D4402-06	2.2
Wax content (%)	ASTM D3344-90	1.82
Flash point (°C)	ASTM D92-02	325
Tests after TFOT		
Mass loss (%)	ASTM D2872-04	0.08
Penetration ratio (25 °C, %)	ASTM D5-06	76.2
Ductility (5 °C, cm)	ASTM D113-07	28.2