Preparation and Evaluation of Composite Flame Retardant Asphalt in Tunnel

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Abstract. Asphalt pavement becomes more and more popular in tunnel engineering, while its flammability is a serious problem that limits its development. In order to obtain a flame retardant asphalt, orthogonal design was utilized to investigate the best flame retardant content of magnesium hydroxide (MH), phosphorus (P) and decabromodiphenyl ethane (DBDPE). Limiting oxygen index (LOI), penetration, softening point and ductility tests were employed to evaluate the flame retardancy and pavement performance of asphalt. The results show that three kinds of flame retardants have positive influence on the low temperature performance and flame retardancy of SBS modified asphalt but not good for its high temperature performance. The best flame retardant content is determined as: 4% MH, 6% P and 8% DBDPE.

1. Introduction
Cement concrete was the main pavement material used in tunnel before 2000 in China [1], and asphalt pavement was increasingly used in highway because of its good performance, comfort and low noise. However, some characteristics of tunnel pavement limited the application of asphalt mixture as the surface material. For instance, the air in tunnel is relatively closed and not easy to circulate, and the space is narrow, which can lead to a serious problem: there will be grave consequences in case of fire disaster. As we all know, asphalt is an inflammable material and releases a lot of heat and harmful smoke when burning. Thus, some researchers have been using flame retardants as modifiers in asphalt binder in order to improve its flame retardancy [2-5].

Wu et al. used halogen flame retardant in asphalt and proved that the asphalt materials had better flame retardancy after adding halogen flame retardant [2]. Xu et al. found that magnesium hydroxide (MH) was a feasible flame retardant used in asphalt mixture [3]. It was reported that MH improved the thermal stability of asphalt and increased its limiting oxygen index (LOI) [4]. Besides, phosphorous flame retardant is also a popular modifier of asphalt binders [5]. In China, since Guonan Wu firstly studied flame retardant asphalt materials in 1989, flame retardant asphalt pavement in tunnel has been widely concerned [6]. While there are still some problems about the application of flame retardant asphalt as tunnel pavement material. Firstly, more effective and safer composite flame retardant needs to be researched and developed because single component flame retardant cannot meet the requirements. Secondly, the composite flame retardant cannot cause too much adverse effect on pavement performance of asphalt.

This paper aims to prepare a composite flame retardant asphalt using SBS modified asphalt, MH, phosphorus (P) and decabromodiphenyl ethane (DBDPE), and evaluate the effect of flame retardant content on the performance of asphalt binder. Orthogonal test was employed to investigate the flame retardancy and pavement properties with different flame retardant content and select an optimal
material ratio. This paper will provide theoretical basis and technical guidance of the application of flame retardant asphalt pavement in tunnel.

2. Materials and methods

2.1. Materials
MH, P and DBDPE were selected as the flame retardants of SBS modified asphalt. MH is white powder with the particle of 5 μm. P is a kind of red powder with the particle of 10 μm. And DBDPE is white powder with the particle of 8 μm. The basic properties of SBS modified asphalt is listed in Table 1.

Table 1. Basic properties of SBS Modified Asphalt

| Project                  | Test result | Technical requirement |
|--------------------------|-------------|-----------------------|
| Penetration (25°C) / 0.1 mm | 58.5        | 40~60                 |
| Softening point / °C     | 75.3        | ≥60                   |
| Ductility (5°C) / cm     | 31.5        | ≥20                   |
| Viscosity (135°C) / (Pa·s) | 2.33        | ≤3                    |
| LOI / %                  | 19          | -                     |

2.2. Preparation of composite flame retardant asphalt using orthogonal design
In order to determine the optimal mass ratio of MH, P and DBDPE, orthogonal design was employed to evaluate the effect of these three factors on the flame retardancy and pavement performance of SBS modified asphalt. In this paper, there were three factors and three levels for each factor, so L9 (3³) orthogonal design table was used according to orthogonal design principle, as shown in Table 2.

Table 2. Orthogonal test plan

| No. | MH content (%) | P content (%) | DBDPE content (%) |
|-----|----------------|---------------|-------------------|
| 1   | 4              | 4             | 4                 |
| 2   | 4              | 6             | 6                 |
| 3   | 4              | 8             | 8                 |
| 4   | 6              | 4             | 6                 |
| 5   | 6              | 6             | 8                 |
| 6   | 6              | 8             | 4                 |
| 7   | 8              | 4             | 8                 |
| 8   | 8              | 6             | 4                 |
| 9   | 8              | 8             | 6                 |

According to Table 2, 9 samples were prepared with this method: preheat SBS modified asphalt to 170°C, then add flame retardant with stirring at 3000 r/min, finally stir the composite flame retardant asphalt with 400 r/min at 160°C to develop.

2.3. Properties tests
The flame retardancy of prepared asphalt was investigated using Limit Oxygen Index (LOI) test by a JF-3 oxygen index meter. It is generally considered that when LOI is less than 21%, the material is combustible, and when LOI is 22% to 27%, the material has self-extinguishing property, while when LOI is larger than 27%, the material has flame retardancy [7-9]. In addition, the pavement performance of prepared asphalt was evaluated by penetration, softening point and ductility tests. The
test results were analyzed by the range analysis to determine the primary and secondary influencing factors of the modified asphalt, so as to obtain the optimum content of each flame retardant.

3. Results and discussion

3.1. LOI

According to the orthogonal experimental scheme, 9 groups of composite flame retardant asphalt were prepared and their LOI was tested. The range analysis was carried out on the test results. The variation law and range value of LOI with three factors are shown in Figure 1.

![Figure 1. Trend of LOI mean and range values](image1)

From Figure 1, the order of influence degree of each factor on LOI of composite flame retardant asphalt is: DBDPE>P>MH. In addition, with the increasing retardant content, the LOI raises up significantly, indicating that the SBS modified asphalt has a better flame retardancy. When the contents of DBDPE, P and MH reach up to 8%, the LOI can be increased to 27.4%, which is 8.4% larger than original SBS modified asphalt. While if three flame retardant contents are only 4%, the LOI is only increased 2.7%. Thus, from the perspective of flame retardancy, the best flame retardant content is that all flame retardants are 8%.

3.2. Penetration

The penetration test was carried out on 9 groups of samples, and the range analysis was carried out on the test results. The change trend and range value of penetration with the content of each flame retardant are shown in Figure 2.

![Figure 2. Trend of penetration mean and range values](image2)

It can be seen from Figure 2 that both MH, P and DBDPE decrease the penetration of SBS modified asphalt, which means that the flame retardant makes asphalt harder. Besides, it is obvious that the
influence on penetration from MH is higher than that from DBDPE, and much higher than P. When the MH content raised from 4% to 6% and then to 8%, the mean penetration value of SBS modified asphalt decreased 0.22 mm and 0.33 mm, respectively. Moreover, the penetration decreased 0.35 mm with the increasing DBDPE content from 4% to 8%. While the penetration only decreased 0.26 mm when P raised from 4% to 8%. Since the penetration of SBS modified asphalt containing the largest flame retardant content still meet the technical requirement (40-60), each plan is feasible.

3.3. Softening point
The Softening point test was carried out on 9 groups of samples, and the range analysis was carried out on the test results. The change trend and range value of softening point with the content of each flame retardant are shown in Figure 3.

![Figure 3. Trend of softening point mean and range values](image)

Softening point reflects the high temperature performance of asphalt, which means that the asphalt with higher softening point have better rutting resistance at high temperature. It can be seen from Figure 3 that both MH, P and DBDPE can increase the softening point of SBS modified asphalt, thus it has a better high temperature performance with flame retardant. It also can be seen that the effect of MH on the softening point of asphalt is more significant than that of P and DBDPE, and the influence of P is the weakest. When the MH content increased from 4% to 6% and then to 8%, the mean softening point of SBS modified asphalt raised up from 80.2°C to 82.5°C and then to 84.4°C, respectively. In addition, the softening point increased by 2.3°C and 0.4°C with the increasing DBDPE content from 4% to 6% and then to 8%. While the softening point of SBS modified asphalt only increased 2.3°C when P content raised form 4% to 8%. Considering this result, more flame retardant could be used for its benefit to the high temperature performance of asphalt. So from this point of view, the best plan is that all flame retardants are 8%.

3.4. Ductility
The ductility test was carried out on 9 groups of samples, and the range analysis was carried out on the test results. The change trend and range value of ductility with the content of each flame retardant are shown in Figure 4.
Ductility at 5°C reflects the low temperature performance of modified asphalt. Asphalt with higher ductility has better crack resistance at low temperature. It is obvious from Figure 4 that both MH, P and DBDPE decrease the ductility of SBS modified asphalt, which means the flame retardant has negative effect on low temperature performance of asphalt. When the content of MH, P and DBDPE raised from 4% to 8%, the ductility decreased 19%, 14% and 11%, respectively. Thus, considering the low temperature crack resistance, the best plan is that all flame retardants are 4%.

3.5. Determination of the best flame retardant content
According to orthogonal test results, SBS modified asphalt with higher flame retardant has better flame retardancy, high temperature performance but weaker low temperature crack resistance and is harder than original asphalt. In order to obtain a composite flame retardant asphalt with good performance, both the pavement properties and flame retardancy should be considered. Since DBDPE is the most favorable one among the three flame retardants for SBS modified asphalt flame retardancy and the least one for low temperature performance, while MH is exactly the opposite, more DBDPE and less MH should be used for asphalt preparation. Thus the best flame retardant content is settled as: 4% MH, 6% P and 8% DBDPE.

4. Conclusions
In this paper, a composite flame retardant asphalt prepared by SBS modified asphalt and three kinds of flame retardants was studied and evaluated by the orthogonal test. The main conclusions can be summarized as follows:

1) Flame retardants can obviously improve the flame retardancy of SBS modified asphalt, among them DBDPE has the best flame retardant effect.

2) Both MH, P and DBDPE have positive influence on the high temperature performance of asphalt but not good for low temperature performance. Besides, flame retardant asphalt is harder than the original SBS modified asphalt.

3) Considering the flame retardancy and pavement properties of asphalt, the best flame retardant content is settled as: 4% MH, 6% P and 8% DBDPE.

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