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Formulation and performance comparison of grouting materials for semi-flexible pavement

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HIGHLIGHTS

- Cement paste and mortar are compared as the grouting materials for SFP.
- Effects of compositions on fluidity, strength and drying shrinkage are analyzed.
- Optimal formulations are respectively determined for cement paste and mortar.
- Properties of paste and mortar meet the requirements with optimal formulations.
- Cement paste with optimal formulation is more suitable as a grouting material.

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ABSTRACT

Semi-flexible pavement has been widely used for good performance, however, few studies have been made on effects of composition and formulation on grouting material. Therefore, this paper focuses on effects of composition and formulation on two typical grouting materials, including cement paste and cement mortar. The optimal formulations of these two materials are determined, and their performances are compared in terms of fluidity, strength and drying shrinkage. The result shows that fluidity, strength and drying shrinkage of cement paste and cement mortar vary with their composition, and both of the two materials can meet the technical requirements in the appropriate formulations. Comparatively, cement paste with its optimal formulation is more suitable as a grouting material for its better performance. The optimal ratio of water to cement is 0.58, the coal ash accounts for 10% and mineral powder accounts for 10%.

1. Introduction

With the increasing traffic flow and traffic loads, early distresses like "rut" usually appear on traditional asphalt roads [1–4]. In order to improve pavement performance and prolong the life of roads, semi-flexible pavement, with open-graded matrix asphalt mixture (void ratio can be as large as 20–28%) filled with special cement paste or cement mortar, has been proposed and analyzed. Semi-flexible pavement, with good mechanical properties, high temperature resistance and excellent fatigue resistance, is unanimously approved and widely used in many countries [5–9].

Bohan Yang et al. [10] analyzed the effects of cyclic wheel load on durability of semi-flexible pavement with different porosities, and established the relationship between loading times and damage variable. Bowen Fang and Tao Xu [11] studied the effects of penetrant, superplasticizer polycarboxylene and SBR latex on cement paste grouting materials of semi-flexible pavement, and determined the appropriate range of formulation. A. Setyawan [12], evaluated the compressive strength of semi-flexible pavement, elaborated relationships between asphalt skeleton, mutual relations grout, aggregate type and size. Q. J. Ding et al. [13] analyzed the performance of semi-flexible pavement in terms of the volume parameters of matrix asphalt mixture, and found that the high-temperature stability and low temperature stability of the semi-flexible pavement material was better than the common asphalt pavement material, and the performances of matrix asphalt mixture with more air void was better. Marcia Lopes Afonso et al. [14] focused on semi-flexible pavement projects based on reclaimed asphalt pavement and waste mud, made a comparison with the traditional hot-mix porous asphalt mixture, and finally recommend appropriate waste mixture. Tianqing Ling et al. [15] comparatively analyzed the road performance of semi-flexible pavement specimens and AC-16 dense-graded asphalt

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Table 1
Chemical and physical properties of Portland cement.

Test items	SiO_2	CaO	Fe_2O_3	MgO	Al_2O_3	SO_3	Loss on ignition
Test results	23.1%	57.6%	3.7%	2.2%	7.1%	2.6%	2.2%
Test items	Initial set		Final set	3-Day compressive strength		28-Day compressive strength	
Test results	150 min		225 min	28.0 MPa		45.7 MPa	

mixture specimens, put forward brittle point temperatures and strain energy density indexes, and found that the semi-flexible pavement specimens had the better low temperature cracking resistance, better anti-fatigue performance and better anti-skid performance.

The above researches mainly focus on the differences between semi-flexible pavement and other traditional pavement in terms of the mixture designs, structures and mechanical performance, but few on the effects of grouting materials, especially on their types, composition and formulation. So in this study, two of grouting materials were selected, including cement paste and cement mortar, and the effects of composition and formulation were investigated to determine the optimal formulation Furthermore, the performances are validated and compared in terms of fluidity, strength and drying shrinkage to recommend the suitable grouting materials.

2. Experiments

2.1. Raw materials

In this study, Qinling 42.5 Ordinary Portland cement, produced in Yaoxian, Shaanxi, was used, which meets the technical requirements according to Test Methods of Cement and Concrete for Highway Engineering, China (JTG E30-2005) [16], and its major chemical and physical properties of Portland cement was shown in Table 1.

The fly ash used in this study meets the requirements of Technical Specifications for Pavement Base Construction, China (JTG/TF20-2015) [17], which is produced in Huxian, Shaanxi province. The major requirements of Technical Specifications include that the fly ash residue on 45 μm square-mesh sieve shall be no more than 12.0%, the water demand ratio shall be no more than 95%, and the loss on ignition shall be no more than 5.0% at 950 ± 25 °C for 15–20 min. The mineral powder was used, and it meets the technical requirements of Ground granulated blast furnace slag used for cement and concrete, China (GB/T18046-2008) [18]. According to the technical requirement, the specific surface area shall be more than 400 m^2/kg, and the 7d and 28d strength activity index shall be larger than 75% and 95%, respectively. The standard sand was produced by China ISO Standard Sand Co., Ltd., the grading and SiO_2 content meet the relative technical requirements in China, and the SiO_2 content is large than 98.0%.

2.2. Sample preparation

Both of the two types of semi-flexible pavement grouting materials, including the cement paste and cement mortar, mainly consisted of cement, coal ash, mineral powder, and water. Besides, fine standard sand was added to prepare the cement mortar contained. Generally, grouting material of semi-flexible pavement shall have good fluidity and ductility, necessary flexural strength and compressive strength as well as better resistance to drying shrinkage. In this study, the recommended fluidity of cement grouting material is from 10 to 14 s, and after 7d standard curing period flexural strength is more than 3.0 MPa and compressive strength is from 10 to 30 MPa [19]. The fluidity tester was shown in Fig. 1, and the test methods are as follows. Firstly, fluidity tester inner wall was rinsed by clean water; then it was filled with 1725 mL of cement grouting material after appropriate amount of cement grouting material was filled and discharged for lubrication, and the outlet was blocked; thirdly, the accurate time slot was recorded, from the moment the cement grouting material began to flow out after the outlet was unblocked to the moment it was totally discharged.

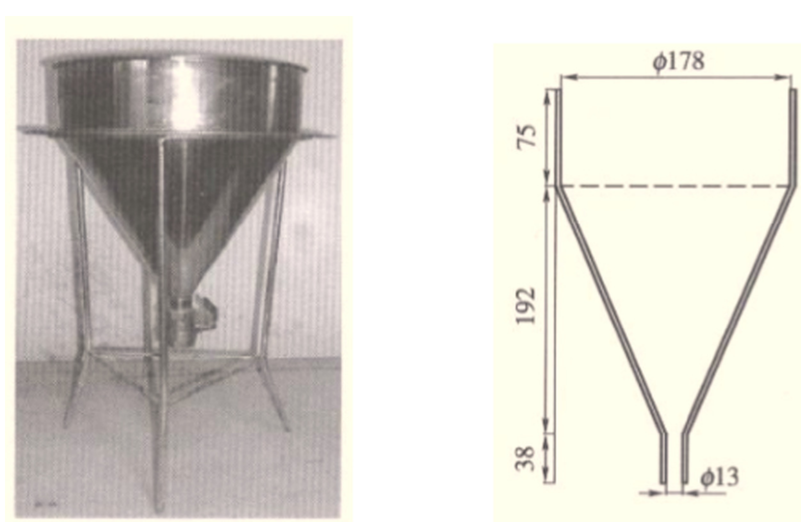
In this study, based on relevant researches [20–21] and adequate previous experiments, the influence factor levels of cement paste and cement mortar were determined, as shown in Tables 2 and 3. The approximate orthogonal arrays was adopted (12, $3^4 4^1$) for each factor level analysis of cement paste while orthogonal table L9 (3^4) was used for each factor level analysis of cement mortar.

The grouting material specimens were prepared with various formulations, and the fluidity, ductility, flexural strength, compressive strength and drying shrinkage were measured, and the effects of composition and formulation on the performances were then analyzed.

3. Test results and analysis of cement paste materials

3.1. Influence on fluidity of cement paste materials

Table 4 shows the analysis results of the fluidity and ductility of selected cement paste. For fluidity index, the best mixture ratio is X4/Y3/Z3, and factors affecting the fluidity, in order of importance, are water-cement ratio, fly ash content, and mineral powder con-



(a) Photo of fluidity tester (b) Schematic diagram of fluidity tester (size unit: mm)

Fig. 1. Fluidity tester used in this study.