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Design and performance validation of high-performance cement paste as a grouting material for semi-flexible pavement

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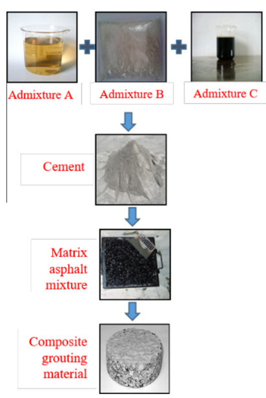
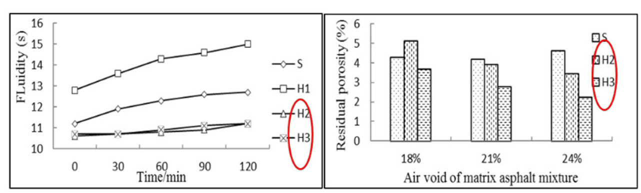
HIGHLIGHTS

- Effects of compositions are analyzed on SFP grouting materials' properties.
- Optimal formulation ranges are determined for HPCP.
- Test method and evaluation indexes are proposed for grouting ability.
- Fluidity, strength, drying shrinkage and grouting ability of HPCP are validated.
- Two of optimal HPCPs are finally recommended as SFP grouting materials.

GRAPHICAL ABSTRACT



Factor level		X	J	P	Q
Recommended value range		0.55-0.57	0.5%-1.0%	10%	0.008%
The recommend ratios of high-performance cement paste	H1	0.56	0.5%	10%	0.008%
	H2	0.56	0.5%	10%	0.0%
	H3	0.56	1.0%	10%	0.008%



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ABSTRACT

Semi-flexible pavement (SFP) has been applied in highway engineering for its good pavement performance. Many researches have been conducted on the performance differences between traditional pavement and SFP, but rarely focus on the composition of SFP materials, especially the composition of grouting materials. Therefore, this paper presents the study of composition design and performance validation of high-performance cement paste (HPCP) mixed with different types and dosages of additives as the grouting material for SFP. Results show that TH-928 polycarboxylate superplasticizer, UEA expansion admixture and ZY-99 saponin air-entraining agents have the different influences on the fluidity, strength and drying shrinkage of HPCP, and HPCP show good working capability with the compound addition of the three additives. Finally, the grouting materials were grouted into the matrix asphalt mixture to prepare SFP materials. The indexes, such as the grouting volume in per unit area, grouting depth and 7d residual porosity, were proposed to verify the grouting ability of selected materials. The verification results show that HPCP has the better grouting ability.

1. Introduction

Semi-flexible pavement (SFP), with open-graded matrix asphalt mixture (void ratio is 20–25%) filled with special cement grouting materials [1], is featured with the flexibility of asphalt concrete

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pavement and the rigidity of cement concrete pavement, which effectively reduces early distresses caused by ever-increasing traffic flow and traffic loads [2–4].

SFP possesses many advantages. Its good stress relaxation can reduce the quantity of temperature joints or even make it unnecessary to set temperature joints, which will greatly improve the driving comfort compared with that of cement concrete pavement. Its stronger rigidity can ensure a higher tolerance of loads without causing any ruts. And its excellent skid resistance owing to the gradation selection of matrix asphalt can greatly improve the driving safety. It also has many other advantages such as good oil-resistance and colourability [5,6]. Thus, SFP has attracted widespread interest of experts and scholars, and been widely used in car parks, gas stations, climbing sections and other special sections [7].

Ding et al. [8] analyzed the differences on mechanical properties and durability between specimens of SFP and those of traditional asphalt concrete pavement with different porosity, and believed that SFP, compared with conventional asphalt concrete pavement, has advantages in high temperature stability and low temperature relaxation capacity, and the greater porosity of matrix asphalt mixture ensures better performance. Bohan Yang et al. [9] analyzed the effects of matrix asphalt mixture void ratio, ratio of water to cement, and base material types and thickness on SFP in cyclic wheel load tests, obtained influential degrees of factors above respectively, and established relational model of loading times and damage variable. S.E. Zoorob et al. [10] researched SFP paved in cool-mixed and cool-spread method, and compared its performance difference with that of traditional hot-mixed and cool-spread SFP in compressive strength, drying shrinkage, indirect tensile stiffness and dynamic creep tests, etc. Hassan et al. [11] prepared different types of grouting materials (cementitious grouts) by using ordinary Portland cement, silica fume and fly ash. etc. and additives, and found it possessed better mobility and higher strength compared with the traditional grouting materials. Setyawan [12] studied the compressive properties of the grout macadams designed, and summed up the relationship of grouted macadams in porous asphalt concrete, relations grout, aggregate type and size. Suhana KOTING et al. [13] adopted two types of polycarboxylic ether polymer and one type of sulphonated naphthalene formaldehyde origin, prepared cementitious grouts with high strength and high fluidity, and analyzed the effects of different doses of additives on the performance. Netter Berg et al. [14,15] adopted from experience with heavy vehicle simulator (HVS) and dynamic cone penetrometer (DCP) testing method, studied hazards of weak layers, interlayers, laminations and/or interfaces in SFP, and further modeled these weak layers and discussed using various examples based on HVS testing and mechanistic pavement analyses.

The above review shows that the currently research is mainly focused on the pavement structure design theory, design methods, and durability of SFP, but few on the material selection and composition, especially on the choice of grouting materials and factors in a detailed way. This paper studies the performance changes of HPCP used as grouting materials and mixed with different additives, analyzed and verified its performance in proper formulation.

In this paper, three common cement additives were selected and mixed into the cement paste to prepare different types of HPCP, and the effects of additives on the fluidity, strength and drying shrinkage of HPCP were analyzed to determine the suitable mixing ratio range. Furthermore, the properties of fluidity, strength and drying shrinkage of HPCP with the optimal formulation were verified. Finally, several indexes were proposed and applied to evaluate and verified the grouting ability of HPCP in SFP.

2. Methodologies

2.1. Raw grouting materials

2.1.1. Portland cement

In this study, Qinling 42.5 grade Ordinary Portland cement produced in Yaoxian, Shaanxi is adopted, meeting the technical requirements in the *Test Methods of Cement and Concrete for Highway Engineering (JTG E30-2005, China)*[16]. Table 1 shows chemical and physical properties of Portland cement.

2.1.2. Cement additives and aggregates

In this study, TH-928 polycarboxylate superplasticizer, UEA expansion admixture and ZY-99 high performance triterpenoid saponin air-entraining agents used as additives are performance qualified through tests; the basalt used as aggregate was produced in Tongchuan, Shaanxi, and its physical properties, mechanical properties meet the requirements specified in *Technical Specification for Construction of Highway Asphalt Pavements* (JTG F40-2004, China) [17]. According to JTG F40-2004, the crushing value of coarse aggregate should be no more than 26%, apparent relative density of coarse aggregate no less than 2.60 g/cm^3, sand equivalent content of fine aggregate no less than 60%, and flat-elongated particles content of mixture aggregate no more than 15%.

2.2. PAC-13 Matrix asphalt mixture

According to specification [18] and our experimental experience, porous asphalt concrete 13 (PAC-13) asphalt mixture is employed as matrix asphalt mixture for SFP with three target porosity, including 18%, 21% and 24%. For the three types of PAC-13 asphalt mixtures, the different gradation of aggregates were designed and determined. In PAC-13 asphalt mixture, the TAFPACK Super (TPS) modified asphalt binder, with A-70 matrix asphalt mixes blended with 12% TPS additive by mass, is applied and its needle penetration is 48.1(0.1 mm), softening point is 88.3 °C, ductility at 5 °C is 47.2 cm, and viscosity at 60 °C is 128925 Pa·s.

2.3. Preparation of HPCP and control sample

Firstly, different content of TH-928 polycarboxylate superplasticizer, UEA expansion admixture and ZY-99 high-performance triterpenoid saponin air-entraining agents were added in cement paste, according to recommended mixing amount of admixture. Through orthogonal test importance order of different additives were obtained; then amount of different additives were optimized, and HPCP was gained.

Pure cement paste, as the control sample consisting of 42.5 grade ordinary portland cement and pure water, was mainly used for performance comparison with HPCP in optimal formulations, possessing the same preparation process and experiment conditions with only difference in additive.

2.4. Specimens preparation of grouting composite materials

Composite grouting material refers to the matrix asphalt mixture filled with grouting materials. In this experiment, large porosity rutting slab filled with grouting materials was used for molding composite grouting material. Specific pouring processes are as follows:

Firstly, 300 mm × 300 mm × 50 mm rutting slabs with different target porosity were prepared based on matrix asphalt mixture, and then were cooled down at room temperature; secondly, HPCP samples H1, H2, H3 and control sample S were respectively