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Slight-expansive road base course binder: Properties, hydration and performance

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HIGHLIGHTS

- A slight-expansive cement was invented as road base course binder RBCB.
- RBCB has similar or better properties and lower cost than 32.5 grade cement.
- More AFt in RBCB hydration products contributes its expansion and strength.
- The road base course stabilized by RBCB has higher properties and less shrinkage.

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ABSTRACT

A new type of slight-expansive cement as road base course binder (RBCB) was prepared to compensate shrinkage of stabilized road base course. The micro calorimeter, XRD, TG-DTA and SEM were used to study the hydration process, the hydration products and the microstructure of RBCB comparing with common 32.5 grade Portland slag cement (P.S 32.5). The results indicate that the RBCB has a slight expansion ratio during hydration process, and it has a much lower dry shrinkage ratio, less hydration heat and a more stable hydration process than P.S 32.5 cement. The main hydration products of this cement are amorphous C-S-H gel and needle like AFt crystal, which interlock among the C-S-H gel and other products and contribute to the strength development of the cement paste. The generating of AFt results in a slight volume expansion, which compensates the shrinkage and contributes to the good volume stability of RBCB. The road base course stabilized by RBCB has higher mechanical properties and lessens the shrinkage crake substantially.

1. Introduction

In China, the semi-rigid road base material is the main type for highway pavement [1,2], and the cement-stabilized or cement-treated granular is the most widely used road base material [1,3]. However, the cement-stabilized road base course has a very strong tendency to crack, and these cracks are very likely to spread to the pavement surface and then give passages to the rainwater in the interface of pavement surface and road base course, mostly resulting into water damage [4]. The dry shrinkage is an inevitable trend for the ordinary cement-stabilized road base materials even after curing for its high dry shrinkage ratio, furthermore, the road base course is not suitable to set expansion joints, so random cracks formed. How to reduce the shrinkage cracks of road base course to avoid the water damage and increase the serviceability of the pavement becomes an important issue and draws extensive attention. Previous studies show that the slight expansive cement can compensate the shrinkage of the road base course. A kind of road base course binder (RBCB) compositing slag, clinker and gypsum was prepared, whereas, the blast furnace slag is very expensive in China currently, generally the conventional RBCB made of blast furnace slag is more expensive than the common Portland cement, while the fly ash is much cheaper in China. 400 million tones of fly ash is produced per annum and it is not fully utilized, especially in the western of China, the utilization ratio of fly ash is extremely low. Enormous amount of fly ash is discharged without any treatment and causes very serious pollution to air, soil and water [5–9]. Utilization of fly ash to produce RBCB is a very effective approach

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to reduce the environmental impact [5], especially, it is an effective way to reduce the carbon emission of cement for this binder contains large volume of fly ash [10,11]. In this paper, a new kind of RBCB mainly made of fly ash instead of blast furnace slag was prepared, of which property was studied comparing with a sort of common 32.5 grade Portland slag cement (P.S 32.5). The micro calorimeter, XRD, SEM and TG-DSC have been employed to characterize the hydration process of RBCB.

2. Materials and methods

2.1. Raw materials

1) Clinker: A Portland cement clinker was obtained from the Cement Company of China Gezhouba Group. Table 1 depicts its physical properties (mixing with some gypsum), the compositions of mineral are listed in Table 2.
2) Fly ash: A class F fly ash used in this work was obtained from Qingshan Thermal Power Plant; its chemical compositions are listed in Table 3.
3) Gypsum: Natural gypsum was obtained from the Cement Company of China Gezhouba Group, its chemical compositions are presented in Table 3.
4) Cement: A kind of common 32.5 grade Portland slag cement (P.S 32.5) was used as a control group in this paper to study the properties, hydration process and hydration products comparing with the new developed RBCB in this paper.
5) Aggregate: aggregate is a kind of broken stone obtained from a highway building site, the aggregate used to prepare road base materials is a composite one with mixing proportion of 1#:2#:3#:4# = 25:28:16:3, the gradations of aggregate 1#, 2#, 3#, 4# and composite are listed in Table 4.

2.2. Experimental methods

1) The fly ash, gypsum and cement clinker were grinded by a 500 mm diameter and 500 mm height standard mill for 3–5 min respectively. Then the fly ash, clinker, gypsum and a kind of additive proportionally were mixed and grinded to the fineness of 0.08 mm sieve residue below 2.0% to prepare RBCB samples, the Blaine specific surface area of the samples were controlled around 350 m^2/kg.
2) Strength of standard cement mortar was measured according to GB/T17671-1999 [12]. The mass ratio of sand and cement was 3.0, and the water/cement ratio (W/C) was 0.5. The dimension of prism specimens for strength measurement is $40 \times 40 \times 160$ mm^3, three prism specimens were cast for each testing points.
3) The deformation ratios of the cement mortar specimens with sand/cement ratio of 3 and water/cement ratio of 0.5 were measured. First, the expansion ratio specimens of the cement cured in water were measured, after 28 days the specimens were moved into a room with 60 ± 1% relative humidity, then their shrinkage ratios were tested, three $20 \times 20 \times 280$ mm^3 specimens were tested for each data point.
4) Normal consistency and setting time of cement paste was tested according to GB/T1346—2001 [13] by utilizing a Vicat apparatus.
5) The mineral phase analysis was examined by X-ray diffraction (XRD, D/Max-RB, Rigaku Inc, Japan) at a scanning rate of 10°/min with the 2θ ranging from 5° to 70°, and measurement accuracy of angle can reach $\Delta 2\theta \leq \pm 0.02°$.
6) The cement hydration heat was analyzed by a thermal conductivity calorimeter for continuous exothermic curve during in 0–72 h. The instrument is micro-calorimeter (SETARAM L80, France), the weight of samples of 500 mg and the water/cement ratio of 1.0 was tested.
7) TG analysis was performed on a differential scanning calorimeter (NETZSCH STA 449C, Germany) for phases identification at a heating rate of 0.1–50 K/min with temperature ranging from ambient to 1000 °C. The accuracy of instrument is within ±1 °C in temperature. Cement paste sample for TG analysis was obtained from the core of the cement paste specimen with water/cement ratio of 0.5, then immersed them in the anhydrous ethanol to terminate their hydration processes, and dried to constant weight at 40 °C in a vacuum before testing.
8) The samples for SEM observation were dried by the same way as TG analysis samples, after each of them were coated with a gold film, A SEM (JSM-5610LV, Japan) was employed to observe their cross-section microstructure.
9) The testing mixture of road base materials were prepared by blending the aggregates, cement and water (with optimum moisture content) together by hand, the mixture was compacted into a 150 mm diameter and 150 mm height cylinder mould to prepare test cylinder specimen, those mixtures with cement must be compacted into cylinder in 1 h after the cement is added in. The relative compaction of the test sample is 98%. The relative compaction is obtained by dividing the dry bulk density of the testing specimens with the maximum dry density; the maximum dry density and the optimum moisture content are determined from the results of the standard Proctor compaction test. The standard Proctor test of road base material are carried out conforming to test method T0804-1994 [26] specifications of Ministry Communication of China, it is very similar to ASTM D698/AASHTO T99 [14]. The unconfined compressive strength test is measured conforming to test method T0805-1994 [26] (similar to ASTM D2166 [15]), the unconfined compressive strength test specimens are sealed in plastic bag and stored in a room at a temperature of 20 ± 2 °C and a relative humility above 95%, they are soaked in the water with room temperature for 24 h before the strength test. Six cylinders are measured for each data point.

The resilience modulus and the splitting strength are done conforming to test method T0807-1994 [26] and T0806-1994 [26], respectively. The splitting strength and resilience modulus of cement stabilized road base materials are measured at 90 days because of faster strength formation, those two factors of the others are measured at 180 days. The modulus of resilience and the splitting strength testing cylinders of the solidified material and other road base materials are formed with a mould of 150 mm diameter and 150 mm height. Nineteen cylinders are tested for each data points of resilience modulus, and nine are tested for each data points of splitting strength. The rate of loading of the unconfined compressive strength and splitting strength tests is 1 mm/min.

Table 2
The chemical and mineral composition of clinker power.

Compositions	Content (%)
C_3S	62.86
C_2S	12.61
C_3A	5.33
C_4AF	14.29
SiO_2	21.74
Al_2O_3	4.88
Fe_2O_3	2.82
MgO	1.83
CaO	62.52
SO_3	3.45
K_2O	1.44
Na_2O	0.30

Table 3
The Chemical composition of fly-ash and gypsum (%/mass).

Raw materials	Fly-ash	Gypsum
Loss	8.01	20.60
SiO_2	52.26	2.76
Al_2O_3	27.40	1.28
Fe_2O_3	3.39	0
MgO	1.10	0
CaO	4.10	31.49
SO_3	0.31	43.53
K_2O	0.14	0
Na_2O	0.12	0

Table 1
Physical properties of clinker.

Fineness (%)	Specific surface ($m^2 \cdot kg^{-1}$)	SO_3 content (%)	Normal consistency (%)	Setting time (hour:min)		Flexural strength (MPa)		Compressive strength (MPa)	
				Initial	Final	3 day	28 day	3 day	28 day
0.4	352	3.07	30.0	1:50	2:35	6.1	9.5	27.6	47.7