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Verification of lime and water glass stabilized FGD gypsum as road sub-base

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ABSTRACT

Flue gas desulfurization (FGD) gypsum is a by-product created when sulfur is removed from flue gases in power plants. The utilization of FGD gypsum as a road sub-base for construction purposes is unsatisfactory when compared with other by-products such as fly ash and steel slag. As a result, FGD gypsum has generally been treated as a waste product and landfill. A new type of semi-rigid road sub-base is proposed, which is a mixture of FGD gypsum, water glass and slaked lime. Laboratory studies of moulded samples of this new material were investigated using different curing methods and measuring unconfined compressive strength, soundness and water stability. The experimental results showed that the road sub-base material reflects excellent mechanical properties and soundness durability. This contributes not only to improved road performance, but also represents a new and improved beneficial use of FGD gypsum.

1. Introduction

In China, a semi-rigid road base made primarily from lime-fly ash stabilized sub-base, lime-fly ash stabilized gravel or crushed stone base, is widely used. These materials create compressive strength, soundness, water stability, etc., that meet the requirements of road engineering projects. There are three types of conventional semi-rigid road base—cement stabilized, lime and industrial waste stabilized and lime stabilized. The common qualities and requirements of these types are shown in Table 1. The lime-fly ash stabilized sub-base and base mentioned above belongs to the second type [1].

There is increasing interest by researchers to develop other base materials to replace the conventional road base type using cheaper and waste materials. Recycled concrete aggregates and crushed clay brick were evaluated for use in unbound sub-base material [2]. Residues produced by incineration of municipal solid waste were also investigated as aggregate substitute in pavements [3].

Recently pavement damages, including cracks and waves, occurred in several highways with conventional design and construction in the southern part of Jiangsu province of China. The authors have conducted an investigation of the causes that resulted in the road damages. After field drilling at the site, it was found that the soil embankment had performed well, but the semi-rigid road sub-base and base were loose and damaged. The field broken samples were taken back to the laboratory for further study. The results indicate that a major component in the failed material is the FGD gypsum and not conventional fly ash that is normally provided by a nearby power plant. FGD gypsum is a relatively new by-product from the power plant compared with fly ash due to the recent installation of FGD equipment in China.

At the end of the 20th century, several researchers have engaged in development of new uses for FGD gypsum. They have identified a number of agricultural and engineering properties of these FGD by-products. Chen et al. [4,5] showed that FGD materials could be used as soil amendments and that plants could be grown safely in soil treated with FGD-$CaCO_3$ if the application is made at least three days to several weeks before planting. Butalia and Wolfe [6] used FGD materials as impervious liners in place of commonly used clay or geo-membranes. The laboratory samples exhibit low permeability (much lower than 1×10^{-7} cm/s) and high strength necessary for liner application. Payette et al. [7] demonstrated the use of FGD material in the stabilization of a portion of a failed highway embankment. A FGD by-product wall was constructed through the failure plane to stop further slippage. The long-term embankment performance of the FGD by-product wall was better than that of the standard construction practices wall or one was made of a mixture soil and FGD by-product. Chandara et al. [8] used waste gypsum, including FGD gypsum, to replace natural gypsum as set retarders in cement. The values obtained for flexural and compressive strength are essentially the same for cement natural gypsum and cement waste gypsum. Bigham et al. [9] conducted swelling tests and pointed out that swelling is one of the most important parameters of concern for FGD by-products

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Table 1
Common qualities and requirements of three types of road sub-base and base for high-grade road construction.

		Cement stabilized	Lime and industrial waste stabilized	Lime stabilized
Sub-base	Compaction	95–97%	95–97%	95–97%
	7d SUCS[a]	1.5–2.5 MPa	>0.6 MPa	>0.8 MPa
Base	Compaction	98%	98%	Not fit
	7d SUCS[a]	3–5 MPa	0.8–1.1 MPa	

[a] SUCS – unconfined compressive strength of soaked samples after 24 h water immersion before curing age.

in engineering uses. Two distinct swelling episodes are exhibited. The first occurs immediately after water is applied due to hydration reactions, especially the conversion of CaO to $Ca(OH)_2$ and $CaSO_4$ to $CaSO_4{\cdot}2H_2O$. The second begins between 10 and 50 days later and involves formation of the mineral ettringite. This may explain the loose and failure of lime-FGD gypsum stabilized base described above. The road sub-base and base contained certain content of the FGD by-product and the swelling deformation destroyed the sub-base's and base's strength capacity and its integrity. This ultimately resulted in the failure of the pavements.

The main objective of the present work is to improve the performance of lime-FGD gypsum stabilized sub-base by using water glass to inhibit the loose and swelling of the sub-base that can lead to pavement damages. The water glass is a common material, which is widely used in chemical engineering, light industry, machine industry, agriculture and construction engineering. In civil engineering, the sodium water glass is mainly used. This could lead to greater use of FGD gypsum in road engineering and encourage Chinese power plants to install flue gas desulfurization technologies to reduce the sulfur dioxide output from the plants. In this paper, the chemical and mineralogical analysis, the compaction characteristics, soundness, curing methods, unconfined compressive strength and water stability of lime and water glass stabilized FGD gypsum road sub-base are presented.

2. Materials and methods

2.1. Raw materials and their characterization

The materials, lime and FGD gypsum, were obtained from the field where pavements'cracks and waves in pavements were noted. The water glass was purchased from Nanjing inorganic chemical plant. The water glass, $Na_2O{\cdot}nSiO_2$, is a liquid and has three different modulus, namely $n = 2.2–2.5$, $n = 2.6–2.9$ and $n = 3.1–3.4$. The content of SiO_2 increases and pH value decreases with the increase in modulus, which may have an effect on the sub-base's soundness, strength and water stability. In the following text, the water glass A, B and C are used to respectively represent water glass modulus $n = 2.2–2.5$, water glass modulus $n = 2.6–2.9$, and water glass modulus $n = 3.1–3.4$. The chemical composition of slaked lime, FGD gypsum and water glass are given in Table 2.

The standard Proctor test was conducted according to test method T0804–94 specification of the Ministry Communication of China, which is similar to ASTM D698/AASHTOT99 [10]. The mixture was compacted into a cylinder by a hammer. The cylinder's volume was 947 cm^3 and the hammer's mass was 4.5 kg and the hammer's drop-distance was 0.457 m. The average compaction power was 2690 J to the mixture. The average compaction power value is first determined, and the blow count and the number of separate layers of hammering the mixture material into the cylinder can be calculated and adjusted according to the average compaction power value.

XRD analysis was performed on a Rigaku D/Max-B diffraction using Cu Kα radiation. Solids were scanned from 2°to 80°with 0.02°2θ step interval. Sulphate content was measured using a barium sulphate gravimetric method.

Table 2
Chemical composition of raw materials.

CC[a] (%)	FGDG[b]	SL[c]	WG A[d]	WG B[e]	WG C[f]
CaO	25.83	71.27	–	–	–
MgO	2.42	3.33	–	–	–
SiO_2	9.90	4.52	⩾29.2	⩾25.7	⩾26.0
Al_2O_3	0.65	3.74	–	–	–
Fe_2O_3	0.30	–	⩽0.05	⩽0.05	⩽0.05
Na_2O	–	–	⩾12. 8	⩾10.2	⩾8.2
SO_3	38.71	–	–	–	–
f-CaO	4.27	–	–	–	–
Crystal water	17.62	–	–	–	–

[a] CC – chemical composition.
[b] FGDG – FGD gypsum.
[c] SL – slaked lime.
[d] WG A – water glass modulus $n = 2.2–2.5$.
[e] WG B – water glass modulus $n = 2.6–2.9$.
[f] WG C – water glass modulus $n = 3.1–3.4$.

The broken samples from the field were also taken back to conduct chemical and X-ray diffraction (XRD) analysis. The XRD analysis suggested that the major mineral form in the field samples was gypsum ($CaSO_4{\cdot}2H_2O$) instead of fly ash.

2.2. Synthesis of lime and water glass stabilized moulded specimens and curing method

2.2.1. Mix and proportion

The dosage of water glass used to make moulded specimens was 0%, 5%, 10% and 15% based on the dry mass of the FGD gypsum and slaked lime mixture. The goal of this study was to investigate the feasibility of using FGD by-product as a road sub-base material and avoiding the poor soundness by water glass, and the proportion of the mixture is not the focus. Then, one laboratory mix was determined. The ratio of FGD gypsum to slaked lime was 3 to 1.

2.2.2. Fabrication of specimens

The samples used to conduct an unconfined compressive strength test and a soundness test were compacted into a $50 \times 50\ mm^3$ cylinder mould near optimum moisture content at degree of compaction of 95%. The mixture's mass was weighed and pressed into the cylinder by a jack, and then the moulded sample was removed from the cylinder and placed in the specific curing condition.

2.2.3. Unconfined compressive strength and curing method

The unconfined compressive strength test was conducted according to test method T0805–94 specification of the Ministry Communication of China (similar to ASTM D2166 [11]). The moulded samples were put into a press machine without lateral confinement after the specific curing time had passed. The rate of samples deformation should be controlled at 1 mm/min, but there was a little difference in the curing method used for this study. The appropriate curing method is a crucial factor for material strength development and future service performance. The conventional curing method of semi-rigid road sub-base and base material, such