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Recycling of Flue Gas Desulfurization residues in gneiss based hot mix asphalt: Materials characterization and performances evaluation

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HIGHLIGHTS

- Gneiss and FGD residues are used as aggregates and filler respectively.
- The adhesion between gneiss and asphalt binder was poor.
- FGD residues should be tightly sealed and pretreated before using in HMA.
- FGD residues strengthen the moisture and crack resistance of gneiss HMA.
- FGD residues worsen the deformation resistance of gneiss HMA.

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ABSTRACT

On the one hand, huge amount of Flue Gas Desulfurization (FGD) residues, produced during scrubbing flue gas, is discarded as solid waste. Such solid waste would cause serious environmental problems. One the other hand, high quality aggregates, such as limestone and basalt, are running out due to the rapid development of highway construction. Ungraded aggregates such as gneiss are therefore considered in China to replace the high quality aggregates. The application of FGD residues as a filler in gneiss based asphalt mixture has benefits both in environmental and economic sides. The main objective of this research was to visualize the raw materials characterization and evaluate the effect of FGD residues on the performance of gneiss based asphalt mixture. X-ray diffraction (XRD), X-ray fluorescence (XRF), Scanning Electron Microscope (SEM), Differential Scanning Calorimetric & Thermal gravimetric (DSC–TG) were used to investigate the features of raw materials. The performance of gneiss based asphalt mixture including high-temperature deformation resistance, low-temperature crack resistance and moisture-induced damage resistance were evaluated. Dynamic creep test, three-point bending test, Retained Marshall Stability (RMS), Tensile Strength Ratio (TSR), Indirect Tensile (IDT) strength and Resilient Modulus (M_R) test were conducted and analyzed. Dissipated Creep Strain Energy to fracture ($DCSE_f$) ratio, fracture energy and model analysis were also used to evaluate moisture resistance, crack resistance and deformation resistance of asphalt mixture respectively. Research results indicate that FGD residues can partly improve the moisture resistance and crack resistance of gneiss asphalt mixture, while it might worse the high-temperature deformation resistance.

1. Introduction

In China, power sources such as heavy oil, coal and electricity power got used in factories, while coal remains the primary feedstock for electrical plants. The situation is similar to USA, about 56% electricity power produced in USA arises from burning coal [1]. Therefore many coal combustion products (CCPs) such as fly ashes, bottom ashes, boiler slags and Flue Gas Desulfurization (FGD) residues are produced [2]. It is required to remove SO_2 produced during coal combustion via scrubbing technologies to meet the clean air regulations. Such procedure creates FGD residues [3]. Two forms, dry and wet desulfurization process, are widely used in factories. Wet desulfurization process is much more popular in large-scale factories. Slurry containing $CaCO_3/CaO$ is adopted as a common sorbent in wet form [4]. FGD residues have been applied

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in many aspects and the typical aspect is agriculture [5]. FGD residues are highly alkaline and it was therefore used to renovate acid soil [6,7] and supply essential elements for plant growth such as sulfur [8]. However, research on the application of FGD residues as filler in asphalt mixture is limited.

In the past decades, Chinese government has invested a lot of money to build the traffic net. The total mileage of expressway reached 104,400 km by the end of 2013 [9]. High quality aggregates such as limestone and basalt get fully used in road construction. It is now becoming urgent to make use of ungraded aggregate such as gneiss in order to alleviate the shortage of the high quality aggregates. Very few research on the performance of gneiss based asphalt mixture can be found in literatures. The adhesion between gneiss and asphalt binder, which is directly linked to many properties of asphalt mixture, was reported as poor [10]. Mineral additives and liquid agents are commonly used to improve a certain property of asphalt mixture [11–13]. The mineral anti-stripping additives, such as fly ash [14], Portland cement [15] and hydrated lime [16], are commonly used to enhance the adhesion property between aggregate and asphalt binder in China. The application of hydrated lime in gneiss based asphalt mixture can be found in the literatures [10,17]. The high alkalinity behavior of FGD residues may also give its potential application in asphalt mixture.

There are many methods to evaluate the moisture-induced damage such as static immersion test [18], boiling water test [19] and net adsorption test [20] for loose mixtures. And stability test [21], RMS [20] and modified Lottman procedure (TSR) [23] for compacted mixtures. RMS and TSR have been widely applied to determine the moisture resistance [24–26]. But the use of a single parameter to evaluate moisture damage was questioned. Birgisson et al. [27] stated moisture-induced damage would result in changes of multiple parameters, not just a single one. Changes in energy parameters such as Dissipated Creep Strain Energy to fracture ($DCSE_f$) were much more reliable to determine moisture resistance than TSR [28]. Bending or tensile test is a common method to determine crack resistance of asphalt mixture. Roque et al. [28] also showed a good correlation between fracture energy limit and the crack growth. Dynamic creep (permanent deformation) test is commonly adopted to evaluate the deformation resistance of asphalt mixture [29].

The high alkalinity behavior of FGD residues gives its potential for using in asphalt mixture. In this research, the feasibility of FGD residues used in gneiss based asphalt mixture was investigated. The effect of FGD residues on the properties of asphalt mixture were analyzed by comparing with that of common fillers such as limestone and Portland cement. Fig. 1 described the experimental design program for this research.

2. Raw materials

Gneiss from Wuxue, Hubei province were used as coarse aggregate and fine aggregate. Fillers used in this research included Portland cement, limestone powder and FGD residues produced during wet desulfurization process. The apparent specific gravities were 3.182, 2.678 and 2.308, respectively. The specific gravity of FGD residues was smaller than that of limestone and Portland cement. Technicians should pay more attention to avoid dust which is harmful to human health when adding FGD residues. Asphalt binder graded 70 (penetration grade), with penetration of 67 (0.1 mm at 25 °C, 100 g and 5 s), ductility of 157 cm (5 cm/min, 15 °C), and softening point of 46.4 °C, from Guochuang Co., Ltd., China was used. The basic properties of aggregate were shown in Table 1.

3. Experiments and methods

3.1. Raw materials characteristics

A D8 Advance XRD from Bruker, German and a JSM-5610LV SEM manufactured by JEOL, Japan were used to observe the mineral phases and surface texture of gneiss respectively. The average chemical component of gneiss and various fillers were determined by an AXIOS XRF from PANalytical.B.V, Netherland. Research in literature has indicated that FGD residues mainly contained $CaCO_3$, $CaSO_4{\cdot}2H_2O$, $Ca(OH)_2$, and $CaSO_3{\cdot}0.5H_2O$ [30]. The release of crystal water may happens during the preparation of asphalt mixture at temperature of 160–180 °C. Therefore it was necessary to evaluate the thermal stability of FGD residues. A DSC & TG system produced by Perkin Elmer Company, USA was used.

3.2. Asphalt mixture design

In this research, asphalt mixtures with nominal maximum size of 26.5 mm were designed by standard Marshall Method. The coarse aggregate (>4.75 mm), fine aggregate (<4.75 mm) and filler accounted for 58%, 38% and 4% by volume of hybrid mineral mixture respectively. Although the specific gravities of fillers were

Table 1
Basic properties of aggregate.

Parameter measured	Gneiss		Criteria in China	Standard
	Coarse	Fine		
Apparent specific gravity	2.748	2.729	⩾2.5	AASHTO T 84/85
Water absorption (%)	0.69	0.82	⩽3	AASHTO T 84/85
Flakiness and elongation (%)	11.2	NA	⩽18	ASTM D 3398
Los Angeles abrasion (%)	23.5	NA	⩽28	BS 812 Part 110
Fine aggregate angularity (%)	NA	49	⩾30	AASHTO T 304
Sand equivalent (%)	NA	58	⩾50	AASHTO T 176

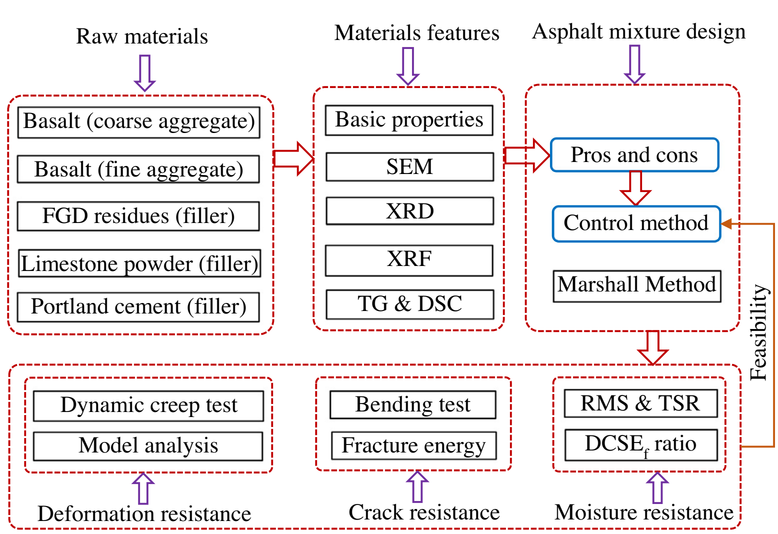

Fig. 1. The experimental design program.