Construction and Building Materials xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Utilization of gneiss coarse aggregate and steel slag fine aggregate in asphalt mixture

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HIGHLIGHTS

- Gneiss and steel slag were used as coarse and fine aggregate respectively.
- Improved technique enhanced fine aggregate angularity and sand equivalent.
- Impurity layer hindered the weathering process of original WSFA.
- Weathering process decreased the porosity of modified WSFA.
- HMA with coarse gneiss and modified WSFA obtained satisfied performances.

ARTICLE INFO

Article history:
Received 13 February 2015
Received in revised form 31 March 2015
Accepted 1 May 2015
Available online xxxx

Keywords:
Steel slag
Gneiss
Material characteristics
Asphalt mixture
Pavement performance

ABSTRACT

Natural resource shortage and environmental pollution issue have promoted the recycling of inferior natural resources and solid wastes in asphalt pavement. While steel slag fine aggregate and inferior gneiss aggregate are rarely used in asphalt mixture in China due to some poor performances. The primary objective of this research was to explore the feasibility of simultaneously using gneiss coarse aggregate and steel slag fine aggregate in asphalt mixture. A new method to improve the quality of steel slag fine aggregate was proposed first. Raw material characteristics directly related to asphalt adhesion and absorption were fully detected then. Performances of asphalt mixture including Marshall stability and quotient, crack resistance, moisture susceptibility, volume stability and deformation resistance were evaluated finally. Results showed that modified WSFA (Weathered Steel Slag Fine Aggregate) presented lower asphalt absorption than original WSFA. Asphalt mixture consist of gneiss coarse aggregate and modified WSFA obtained better crack resistance, moisture resistance, volume stability and deformation resistance.

1. Introduction

Hot-mix Asphalt (HMA) mixture contains more than 90% of mineral aggregates by weight [1]. Therefore the construction and maintenance of asphalt pavement have consumed enormous natural resources. It is estimated that only in 2010 about 630 Mt of HMA and 560 Mt of natural aggregates were consumed in China [2]. Recycling of inferior natural resources [3] and some wastes such as demolition waste [2,4], steel slag [5–7], reclaimed asphalt pavement (RAP) [8,9] etc. in asphalt mixture is a promising way to reduce the demand of high-quality natural resources.

Steel slag, an industrial waste, accounts for 13% of raw steel output [10]. The feasibility of using steel slag coarse aggregate in asphalt mixture has been well evaluated in literature. Results showed that the introduction of steel slag coarse aggregate in asphalt mixture improved the mechanical characteristics [11,12] and pavement performances such as moisture stability [6,10], skid resistance [5,7,10], deformation and crack resistance [5,10,13]. While the use of steel slag fine aggregate in asphalt mixture is rarely reported due to some poor performances and high cost factors. On the one hand, the angularity and cleanliness of steel slag fine aggregate get worse during storage [7,14]. Steel slag contains some free lime (f-CaO) and its hydration results in volume instability. Limited research suggested that the total expansion of steel slag should be within 1% when it was used in asphalt mixture [15]. On the other hand, steel slag is porous materials [5]. Excessive asphalt absorption caused by pores leads to high cost [5,7]. Therefore HMA with steel slag fine aggregate or with 100% steel slag was not suggested [16].

The adhesion behavior between gneiss aggregate and asphalt, directly related to many properties of asphalt mixture such as

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http://dx.doi.org/10.1016/j.conbuildmat.2015.05.070
0950-0618/

moisture susceptibility and crack resistance, was proved to be poor [3]. This was because gneiss was acid rocks and the surface of gneiss aggregate was much smoother than commonly used aggregate [3]. Acid feature and layered structure result in inferior chemical and physical adhesion between gneiss and asphalt binder. Replacing the fine part of gneiss mixture by high-quality fine aggregates [17] or using anti-stripping agents [3,18,19] in gneiss mixture are two common methods to improve the adhesion behavior.

The objective of this research was to explore the feasibility of simultaneously using gneiss coarse aggregate and steel slag fine aggregate in asphalt mixture. A new method to improve the quality of steel slag fine aggregate was proposed first. Raw material characteristics related to asphalt adhesion and absorption were fully detected and analyzed then. Performances of asphalt mixture were evaluated finally. Unlike common test procedure, crack resistance and moisture susceptibility were characterized by fracture energy and its retained ratio respectively. Volume stability and deformation resistance were determined by improved methods. Fig. 1 describes the experimental design program for this research.

2. Materials and methods

2.1. Materials

Gneiss coarse aggregate and three types of fine aggregates as limestone, original WSFA (Weathered Steel Slag Fine Aggregate) and modified WSFA were used. Gneiss and limestone were from Wuxue, Hubei province. Steel slag is a Basic Oxygen Furnace (BOF) slag and was provided by Metallurgical Slag Corp., Wuhan Iron and Steel. Modified WSFA samples consist of two parts: size beyond and below 1.18 mm and the two parts were mixed according to their proportions in asphalt mixture. The basic physical properties of aggregates were tested according to ASTM standards and results were shown in Table 1.

The preparations of original WSFA and modified WSFA were as following. It was clearly observed that particles in steel slag fine aggregate (size below 4.75 mm) produced by crushing wet steel slag block were seriously coated by impurities (fine powder, dust and sludge). Weathering process was a common way to improve the volume stability of steel slag [20]. The coating layer consists of complex impurities solidified on the surface of steel slag particles during weathering (see picture a in Fig. 2). This was because steel slag contained some silicate minerals [21] and the hydration of silicate minerals made impurity layer solidified. Weathered slag tightly covered by impurity layer was called original WSFA. The outline of original WSFA tended to be elliptical sphere, which resulted in low fine aggregate angularity (FAA) (see Table 1). The low sand equivalent (SE) in Table 1 also indicated that the surface of original WSFA contained much clay or other free impurities. Except for production issue, random stack and lack of effective management also contributed to it.

A new method to improve the quality of steel slag fine aggregate was proposed in this research. Newly crushed steel slag fine aggregates were first subjected to vibrating sieve and they were divided into two parts. The part with particle size larger than 1.18 mm was further treated by drum sieve. Four high-pressure water jets, mounted on the top and at the bottom of inlet and outlet ports respectively, were adopted to clean particles and the sewage contained impurities was discharged through sieve pores (see picture b in Fig. 2). Cleaned particles with size beyond 1.18 mm were obtained. Two parts (size beyond and below 1.18 mm) were then subjected to weathering treatment. The part with size below 1.18 mm was easily agglomerated during weathering, therefore stir and smash were needed. The two parts treated by this method were named as modified WSFA. The termination weathering periods for original WSFA and modified WSFA both were 12 months.

Limestone filler with a hydrophilic factor of 0.76 and base asphalt binder graded 70 (penetration grade), with penetration of 66 (0.1 mm at 25 °C, 100 g and 5 s), ductility of 151 cm (5 cm/min, 15 °C), and softening point of 46.9 °C, were also used in this research.

2.2. Methods

2.2.1. Raw material characteristics

The feasibility of simultaneously using gneiss coarse aggregate and steel slag fine aggregate in asphalt mixture was theoretically explained according to previous research results and material characteristics detected in this research. Physical phases and chemical composition were measured by D8 Advance X-ray diffraction (XRD) and Axios X-ray fluorescence (XRF) respectively. Surface characteristics including surface texture, cumulative pore volume and pore size distribution were also evaluated. Surface texture was observed by JSM-5610LV scanning electron micrograph (SEM). Pore characteristics were analyzed based on sorption isotherm obtained from nitrogen adsorption test.

2.2.2. Asphalt mixture design

Superpave procedure was adopted to design asphalt mixture with the maximum nominal size of 12.5 mm in this research. The particle compositions for various mineral materials and gradation curves for different mineral mixtures were shown in Fig. 3. Considering that only the fine aggregate type in each mixture was different, the names of fine aggregate were adopted to describe asphalt mixtures in later sections. Volume control method was used in order to consistently maintain the volume composition of different mixtures. Therefore the gradation curves for different mixtures were not completely overlapped in the coordinate system of mass passing percent. The proportion of gneiss coarse aggregate was 49% by volume in various mixtures. Original WSFA and modified WSFA both accounted for 47% by volume. And limestone powder fillers was 4% by volume.

2.2.3. Marshall test

Marshall test was conducted according to ASTM D6927 [22]. The specimens with diameter of 100 mm and thickness of 63.5 mm were prepared by coring and cutting from cylindrical specimens compacted in Superpave gyratory compactor (SGC). The air voids of specimens were 4%. Specimens were first immersed in hot water bath of 60 °C for 30 to 40 min, then the Marshall stability (kN) and flow (mm) of specimens were measured by HM-3000 master loader with constant

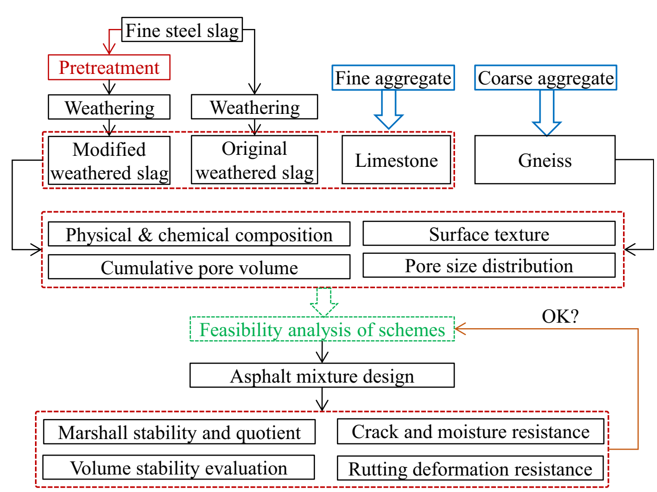

Fig. 1. The experimental design program for this research.

Table 1
The basic physical properties of aggregates.

Parameter measured	Coarse		Fine			Requirements in China
	Gneiss		Original WSFA	Modified WSFA	Limestone	
Size range (mm)	19–9.5	9.5–4.75	4.75–0	4.75–0	4.75–0	
Apparent specific gravity	2.742	2.736	3.231	3.279	2.694	⩾2.5
Flakiness and elongation (%)	11.6	14.9	NA	NA	NA	⩽18
Los Angeles abrasion (%)	22.1	22.1	NA	NA	NA	⩽28
Fine aggregate angularity (%)	NA	NA	38	50	48	⩾30
Sand equivalent (%)	NA	NA	53	66	62	⩾50