Construction and Building Materials 180 (2018) 605–613

Contents lists available at ScienceDirect

Construction and Building Materials

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

Environmental aspects and pavement properties of red mud waste as the replacement of mineral filler in asphalt mixture

Jizhe Zhang [a], Shengjie Liu [a], Zhanyong Yao [a], Shaopeng Wu [b], Hongguang Jiang [a,*], Ming Liang [a,*], Yaning Qiao [c]

[a] School of Qilu Transportation, Shandong University, Jinan, 250061, China
[b] State Key Laboratory of Silicate Materials for Architectures, Wuhan University of Technology, Wuhan 430070, China
[c] Department of Civil and Environmental Engineering, University of New Hampshire, W137 Kingsbury Hall, 33 Academic Way, Durham NH03824, US

HIGHLIGHTS

- Natural mineral filler was replaced by red mud to prepare asphalt mastic.
- Leaching toxicity and radioactivity of red mud waste were evaluated.
- Improved stiffness and rutting parameter of asphalt mastic indicated improved rutting resistance.
- The Sintering RM had the capability to improve the elastic recovery of asphalt mastic.
- The red mud waste can be concerned as a secondary resource to replace the natural mineral filler for asphalt pavements.

ARTICLE INFO

Article history:
Received 22 February 2018
Received in revised form 3 May 2018
Accepted 30 May 2018

Keywords:
Asphalt mastic
Red mud
Leaching toxicity
High-temperature properties
Pavement

ABSTRACT

The red mud waste generated from the alumina refining industry, which remains high alkalinity and problematic pollutants, is occupying considerable land resource and causing significant environmental problems worldwide. Instead of landfills, the utilization of the red mud waste as a substitution of mineral filler in asphalt pavement mixtures has been investigated in this study. The physical and chemical properties of the red mud waste were first characterized. The experimental tests including softening point, penetration, dynamic shear rheometer (DSR) and multiple stress creep recovery (MSCR) were then conducted to evaluate the properties of asphalt mastic. Based on the results on leaching toxicity and radioactivity, the red mud waste had no risk to be used as a building material. Moreover, the addition of red mud waste can improve the stiffness and elasticity of asphalt mastic. The increased rutting parameter and the decreased accumulated creep strain were further found, especially the Sintering RM. In addition, the Sintering RM had the capability to improve the elastic recovery of asphalt mastic, while the Bayer RM had limited contribution to this behavior. Consequently, the red mud waste can be concerned as a secondary resource to replace the natural mineral filler for asphalt pavements.

1. Introduction

Since 2016, the total expressway length in China has been over 130 thousand km and this is still increasing gradually with time. In the field of road construction, asphalt mixture is the dominant material for surface paving course. It is a composite material which is produced in a predetermined ratio of aggregate, bitumen and filler at high temperatures and followed by compaction [1,2]. As an integral part of asphalt mixture, the natural mineral filler is in a great demand with rapid development of road construction, especially in developing countries [3]. However, due to negative environmental pollution during crushing and ball-milling processing, many filler plants were closed in China and the filler price followed an obvious increase. Consequently, it is of great importance to search other alternative materials which can replace the natural mineral filler in asphalt mixture.

Red mud (Bauxite residue) is a by-product generated in alumina (Al_2O_3) refining process, which is based on the reaction of bauxite with sodium hydroxide under high temperature and pressure [4]. Generally, the production of 1 ton of alumina results in 1.5–1.6 tons of red mud. Over 120 million tons of red mud is generated annually throughout the world [5], in which China occupies nearly

* Corresponding authors.
E-mail addresses: honguang_jiang@sdu.edu.cn (H. Jiang), ming.liang@sdu.edu.cn (M. Liang).

https://doi.org/10.1016/j.conbuildmat.2018.05.268

60% of them. Due to its highly alkaline (pH 9–12.5), red mud is thus classified as a corrosive hazardous material in some countries [6,7]. The NaOH and metallic oxide-bearing impurities are able to precipitate out from the red mud and contaminate the surface and underground water resources [8]. Inadequate disposal of red mud pose a potential to direct contact with fauna and flora, which eventually threat to human health and environment [9]. Furthermore, evaporation of alkali components could generate highly alkaline rainfalls [10]. Consequently, enormous accumulation of red mud not only occupies land resources, but also poses a serious environmental problem [7].

In the literature, it has been reported that a target has been set by Chinese government to utilize 20% of fresh red mud by the end of 2015 [11]. Substantial research and field application have been developed for the utilization of red mud in some field. Due to its high metallic oxide content and presence of alkalis, many studies have attempted to recover alumina, soda, ferric and titanium oxide from red mud [12,13]. However, the material recovery strongly depends on the metal present in the red mud and the high costs and low yields prevent its large-operational application. Because of its high specific surface area and hydroxides content, red mud has been also considered as an absorbent for water treatment [14]. By using red mud, pollutants such as dyes, toxic cations, organic matter and heavy metals can be removed from aqueous solutions [15,16]. In recent years, some researchers have been focused no incorporating the red mud in construction materials such as cement [17], clay-based ceramic [18], lightweight aggregate [19] and bricks [20]. However, the use of red mud in Portland cement has been terminated due to the limits of $Na_2O + K_2O$ in new standard [21]. Also, the bricks appeared with red mud appeared efflorescence with the passage of time, which hurdle the utilization of red mud [11]. Another factor which limits the utilization of red mud is the transport distance between the refinery and the production sites as the transporting cost is one of issues. Despite the technology development in the red mud application, the commercialization of applying red mud is still under consideration. Till now, the accumulated red mud in the world is over 2.7 billion tons and China occupies nearly 60% of them. So, the utilization of red mud is an enormous challenge.

According to the reported studies, red mud has been considered as a construction material, but there are a few reports on the utilization of red mud in asphalt mixtures. Therefore, the objective of this research is to investigate the possibility of utilizing red mud to replace mineral filler in asphalt pavement mixture. Two types of red mud materials produced from Sintering process and Bayer process were selected. The red mud materials and mineral filler at predetermined ratios were added to the hot bitumen to prepare asphalt mastic. Experimental tests such as Softening Point, Penetration, Dynamic Shear Rheometer (DSR) and Bending-Beam Rheometer (BBR) were conducted to characterize the influence of red mud on the mechanical performance of asphalt mastic at both low and high temperatures. The optimum proportion of red mud was evaluated and obtained based on the test results.

2. Materials and methods

2.1. Materials

2.1.1. Bitumen

70# base bitumen supplied by Huarui Asphalt Company in Shandong province, PR China was used to prepare asphalt mastic. The bitumen was strictly evaluated based on Chinese standards JTG E20-2011, and the results are presented in Table 1.

Table 1
Physical properties of bitumen.

Bitumen test	Result	Technical requirement	Test standard
Softening point [°C]	46.2	≧46	T0606
Penetration [25 °C, 0.1 mm]	68.2	60–80	T0604
Ductility [15 °C, cm]	>100	≧100	T0605
Viscosity at 60 °C [Pa s]	208	≧180	T0625
Flash point [°C]	293	≧260	T0611
Solubility in C_2HCl_3	99.73	≧99.5	T0607
Relative density at 15 °C	1.004	–	T0603

2.1.2. Red mud

Two types of red mud materials produced from sintering process and Bayer process were obtained from Shandong Aluminium Industry co., ltd. In this company, over 150 million tons of red mud is accumulated and occupies over 3 million m^2 of arable land, as shown in Fig. 1. In light of using red mud to replace natural mineral filler, these two red mud materials were first dried in an oven and then sieving passing the size of 0.075 mm screen. The morphology of these two red mud powders was shown in Fig. 2. It can be seen that the Sintering RM was dull gray, while the Bayer RM was dark red. One type of commonly used natural mineral powders produced from a limestone quarry (Wenzu in Shandong Province) was used as a reference filler. The basic properties such as specific gravity and PH value were measured and shown in Table 2. It can be seen that these three filler samples had similar specific gravity in the range of 2.55–2.85 g/m^3. Higher PH value of red mud samples demonstrating strong alkali component. As these two red mud materials were first used to replace mineral filler in asphalt mixtures, their detailed physical and chemical characterization were applied in the following section.

2.2. Asphalt mastic design and preparation

The asphalt mastics were prepared by using bitumen and fillers at a mass ratio of 50:50%. With the view of evaluating the influence of red mud, the natural mineral filler was replaced by the red mud materials at 0%, 25%, 50%, 75% and 100% by weight of mineral filler. The asphalt mastics were prepared in a metal container with the maximum capacity of 2 kg. The preparation process of asphalt mastics was: the bitumen was first heated in an oven at 150 °C for 1 h until melt; the mineral filler and red mud in predetermined ratio were then added to the bitumen and uniformly mixed at a temperature of 150 °C for 0.5 h at the speed of 1000 rpm; and, the well blended asphalt mastics were stored at room temperature for further tests.

2.3. Experimental program

2.3.1. Particle size distribution

The particle size distribution of red mud and mineral filler was determined by using a Laser Particle Size Analyzer (LS230). The theory of this method is based on the interaction between monochromatic light and individual particles. During testing, the scattered laser light by a set of monodispersed particles was analyzed by a reverse optical scattering-based model to provide a sphere-equivalent size diameter distribution [22].

2.3.2. Specific surface area and pore size distribution analysis

The specific surface area of powders were measured through a dynamic vapour sorption system (Surface Measurement System, Middlesex, UK). By using this approach, the particles mass increases due to the adsorption of probe vapour at their surface and this increased mass is then measured by a sensitive balance. The specific surface area of the particles was calculated by using the Brunauer-Emmett-Teller (BET) approach as shown in Eq (1) [23]:

$$SSA = \left(\frac{n_m N_o}{M}\right)\alpha \tag{1}$$

where SSA is the specific surface area (m^2/g), n_m is the monolayer specific amount of vapour adsorbed on the surface of aggregate (mg), N_o is Avogadro's number (6.022 × 1023 mol^{-1}), M is the molecular weight of the vapour (g/mol) and α is the projected or cross-sectional area of the vapour single molecule (m^2).

The Barret-Joyner-Halender (BJH) method was employed to determine the pore size distribution of powders. This method uses the N_2 desorption branch of the isotherm and relates the amount of adsorbate desorbed to the average size of pores, which is affected by this desorption with the detailed introduction of this test can be seen in [24].

2.3.3. Chemical and mineral compositions

Chemical compositions of red mud and mineral filler were measured by X-ray fluorescence spectroscopy (XRF) (PHILIPS MAGIX) [25]. The X-ray was generated from rhodium target at an accelerated voltage of 20 kV. The spectra were then collected using a collimator with the smallest aperture. Finally, the spectra were then analyzed for elemental composition according to the calibrated procedure [9].