Energy xxx (2016) 1–9

Contents lists available at ScienceDirect

Energy

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

Energy savings and reduction of CO_2 emission using $Ca(OH)_2$ incorporated zeolite as an additive for warm and hot mix asphalt production

Ajit Sharma, Byeong-Kyu Lee*

Department of Civil and Environmental Engineering, University of Ulsan, Daehakro 93, Namgu, Ulsan, 680-749, Republic of Korea

ARTICLE INFO

Article history:
Received 14 November 2015
Received in revised form
15 February 2016
Accepted 17 March 2016
Available online xxx

Keywords:
CaZ
CO_2 emission
Energy saving
Mixing temperature

ABSTRACT

WMA (Warm-mix asphalt) has been gaining popularity primarily because of its lower energy consumption and reduced air emissions. This study investigated the energy saving and CO_2 emission reduction properties of $Ca(OH)_2$ incorporated zeolite (CaZ), synthesized by a sol–gel method and used as an additive for ASCON (asphalt concrete) production at different temperatures (120, 140 and 180 °C). The addition of up to 6 wt.% CaZ lowered the ASCON production temperature to 120 °C, leading to a production cost saving of 0.882 million US$/y, and an energy saving of 24,831 GJ/y for 140,000 Tonne/y compared to conventional HMA (hot mix asphalt) production at 180 °C. In addition, CO_2 emission was reduced from 7500 ppm for HMA production to 500 ppm for WMA production at 120 °C. The significantly lower energy consumption and CO_2 emission resulting from addition of CaZ composite are associated with easy release of water vapor due to the dendrite nano structure of the synthesized CaZ, accompanied by easy volume expansion and asphalt viscosity reduction.

1. Introduction

Most paved roads in modern countries consist of asphalt pavement. ASCON (Asphalt concrete) production is required for construction or repair of asphalt pavement roads. Asphalt is a sticky, black and highly viscous liquid or semi solid of petroleum which consists of saturated hydrocarbons, high molecular weight phenols, heterocyclic compounds, asphaltenes and aromatic compounds such as naphthene [1]. Asphalt (bitumen) is a liquid fuel that consists of complex hydrocarbon molecules. It is also called carbon intensive which is a secondary source of CO_2 emissions [1a,b]. Asphalt production is the second most energy-intensive manufacturing industry in the world. A large amount of CO_2 and other gaseous pollutants are emitted from ASCON production or asphalt pavement processes which require high temperature and significant energy consumption [2,3]. The mixing temperature for asphalt mixture production can be divided into two categories; (a) low temperature range at 110–140 °C for WMA (warm mix asphalt) and (b) high temperature range at 150–180 °C for HMA (hot mix asphalt) [4]. HMA production and pavements emit large quantities of greenhouse gases including CO_2, CH_4, and N_2O [5]. Thus, HMA production is considered a main source of CO_2 emission in road or highway construction, which is unfavorable for developing a low-carbon economy [6]. According to greenhouse gas emission statistics of the IEA (International Energy Agency), 25% of global CO_2 emission is produced by the transport industry network [7]. The Republic of Korea was known as one of the largest CO_2 emitting countries with an estimated 15.4% of the total CO_2 emissions in 2010 from the transport sector [8]. Hence, considerable effort is currently focused on developing new technologies, smart materials, regulatory documents and strategies for CO_2 emission reduction and energy consumption [8a]. According to the Korean air pollution report, it was found that about 151,631,376 t CO_2 were released from highway network construction [9]. It appeared that construction of 1 km of expressway produced about 9729 t CO_2 emission per lane [10]. WMA with a production temperature of 110–140 °C has become an advanced technology for ASCON in the world because of lower fuel cost, less CO_2 emission, and reduced asphalt oxidation as compared to HMA produced at 150–180 °C [11]. WMA technology can be classified based on the utilization of organic or chemical additives and the utilization of water [12,13]. The WMA technologies work by lowering the asphalt viscosity which allows proper mixing with aggregate surfaces, and lowering

* Corresponding author. Tel.: +82 52 259 2864, Fax: +82 52 259 2629.
E-mail address: bklee@ulsan.ac.kr (B.-K. Lee).

http://dx.doi.org/10.1016/j.energy.2016.03.085

the mixing temperature required for satisfactory workability of the ASCON mixture. The mixing temperature of WMA production is usually lower about 30–60 °C than that of HMA production. Thus, WMA production can reduce around 30% energy consumption resulting in lower emissions of harmful gases and dust. One concern of the WMA is to keep good workability as compared to HMA, which should be solved in WMA production. The workability is completely depending on temperature and additives, which can make proper asphalt mixing at even lower mixing temperature [13a,b]. Based on production costs, air pollutant emissions and workability, the overall performance of WMA pavement is equal to that of HMA pavement [4]. However, only a few studies have been made analyzing the effect of WMA additives, binders and mixtures on production cost, pollution, energy consumption and WMA performance [14–17].

Synthetic zeolite is hydrothermally crystallized and holds 21% (by mass) of water, which is one of the most common additives for WMA production [18]. Hypothetically, the zeolite can release water vapor by creating foam which reduces the viscosity and increases the workability of asphalt mixing. Zeolite facilitates better coatings of the bitumen on aggregates leading to improved bonding between asphalt and aggregates [19]. Zeolite is also a multifunctional material which is used in many industrial products such as gas absorbers, chemical sieves, adsorbents and catalysts [20,21]. In recent research, OSDA (organic structure directing agent) based beta zeolite was used for CO_2 adsorption-desorption under moderate temperature [22]. The 13X-zeolite was used for pressure swing adsorption of CO_2 and separation from gas mixtures containing methane and CO_2 [23]. Wang et al. reported in 2011 that zeolite based composites are the best materials for capturing CO_2 from the air environment [24]. The relevant studies recently reported that copper based oxygen carriers can be utilized for CO_2 sequestration at high purity through chemical looping combustion cycle, which can lead to CO_2 emission reduction [1a]. However, emission reduction of CO_2 is limited by weak van der Waals attractive forces between CO_2 and adsorbent and low CO_2 selectivity in gaseous mixtures [25]. Thus, further study of effective methods for releasing a large amount of water vapor during asphalt mixing, and simultaneously removing CO_2 through sorption or catalytic activity during ASCON production by WMA technology is needed. Calcium hydroxide ($Ca(OH)_2$) is used in multiple applications such as ASCON production and CO_2 sorption. There is considerable information in the literature on calcium hydroxide's ability to control water sensitivity and its well-accepted ability as an anti-strip to inhibit moisture damage [26]. Recent studies also demonstrate that $Ca(OH)_2$ acts as an active filler and anti-oxidant in the HMA process [27]. Additionally, $Ca(OH)_2$-based sorbents have been considered to be promising candidates for CO_2 sorption/capture capacities under the conditions for steam reforming of petroleum. They are also considered to be the best candidates, thermodynamically, among metal oxides for CO_2 capture in zero emission power generation systems [28,29].

Thus, the nanocomposite of zeolite with $Ca(OH)_2$ may improve the water resistivity and facilitate the mixing of aggregates with bitumen at low temperature leading simultaneously to saving energy and controlling CO_2 emission through catalysis/capture phenomena. In the current study, we hypothesized that the $Ca(OH)_2$ doped zeolite nanocomposite (CaZ) can be applied for ASCON production as a chemical additive in the foaming process to control asphalt mixing temperature, and as a binder to control the down aging process. We also hypothesized that CaZ can act as a catalyst/sorbent to capture CO_2 at different temperatures. This study analyzed the application feasibility of synthesized CaZ as HMA and WMA additives for ASCON production at different temperatures and focused on evaluating CO_2 emission and energy consumption. The study also aimed to analyze energy cost saving and CO_2 emission reduction capacity of CaZ for WMA production at 120 °C, which would be considered the most desirable ASCON production temperature.

2. Experiment and analysis

2.1. Chemicals used

NaOH (Merck), $NaAlO_2$ (Merck), Silica solution and $Ca(OH)_2$ were purchased from Daejung Chemical and Metals Co. Ltd. All the test solutions were prepared with double distilled H_2O using analytical grade chemicals.

2.2. Synthesis of CaZ nanocomposite

$Ca(OH)_2$ was doped during the sol–gel process of producing zeolite as shown in the schematic in Fig. 1 A mixture (1:1) of 4.375 g of NaOH and $Ca(OH)_2$ with 1.837 g sodium aluminate ($NaAlO_2$) salt in H_2O was aged for 5 h with stirring at 200 rpm. Subsequently, 82.5 g silica sol was added drop wise into the mixture, and the mixture was stirred at room temperature for 12 h. The homogenous mixture was then heated for 24 h at 180 °C under autogenous pressure. The solid product was centrifuged and washed with deionized water until attaining pH 7. The CaZ nanocomposite was dried at 80 °C for 10 h.

Zeolite was synthesized using the above process and similar conditions without $Ca(OH)_2$.

2.3. Analysis of material characteristics

FTIR (Fourier transform infrared) spectra were recorded over the wavenumber range from 500 to 4000 cm^{-1} on a Nicolet Nexus 470 spectrophotometer. XRD (X-ray diffraction) analysis was carried out

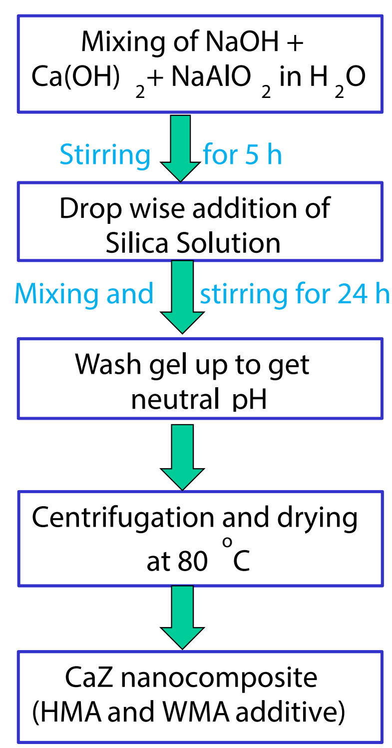

Fig. 1. Schematic procedure for CaZ synthesis.