Journal of Cleaner Production 199 (2018) 101–111

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Emulsified cold recycled mixtures using cement kiln dust and coal waste ash-mechanical-environmental impacts

Mohsen Amouzadeh Omrani, Amir Modarres*

Department of Civil Engineering, Babol Noshirvani University of Technology, Shariati St., Babol, Iran

ARTICLE INFO

Article history:
Received 18 March 2018
Received in revised form
13 July 2018
Accepted 13 July 2018
Available online 17 July 2018

Keywords:
Emulsified cold recycled mixture
Cement kiln dust
Coal waste ash
Mechanical properties
Environmental impacts

ABSTRACT

Cold recycling is a widely recommended asphalt pavement rehabilitation technology with potentially significant economic and environmental benefits. One of the advantages of cold recycling is that its operations are performed at ambient temperature. However, there are still some concerns regarding the use of emulsified cold recycled mixtures (ECRMs). These pavements are susceptible to problems such as raveling, stripping, low initial strength, and long curing time, which are often countered by the use of additives. This study examined the mechanical outcomes and environmental implications of using cement kiln dust (CKD), which is a byproduct of cement production plant, and coal waste ash (CWA), which is obtained by igniting coal waste, in ECRMs as additives. The effects were compared with the additive-free or reference mixture and the mixtures with 1% and 2% cement content. To evaluate the mechanical properties, Marshall stability, indirect tensile strength and moisture susceptibility tests were performed on the specimens of different ages at different temperatures. Environmental impact was assessed using the modified toxicity characteristic leaching procedure (MTCLP) test. Finally an economical-environmental analysis was performed on designed pavements with each type of ECRM. The results showed that the combined use of CKD and CWA improved the mechanical properties, especially after prolonged curing periods. In some cases, this improvement was even greater than the improvement resulting from the addition of cement. The results of the MTCLP test showed that even after five extractions, the concentration of heavy metals in the leachate of CKD- and CWA-containing mixtures remained below the regulatory levels. Overall, it was found that using CKD and CWA as additives in ECRMs had remarkable economical and environmental benefits, especially if they are employed together.

1. Introduction

Cold recycling is a technology involving the rehabilitation of asphalt pavements at ambient temperature and consequently with reduced use of energy, lower consumption of fossil fuels, and reduced emission of greenhouse gases (Ameri and Behnood, 2012). This technology can also assist the pavement industry to face another emerging challenge, that is, the gradual depletion of high-quality mineral resources required for its operations (Lin et al., 2017). Cold recycling also reduces the noise pollution by decreasing the lorry transport of materials, which are required for traditional hot mix asphalt pavement (Zhu et al., 2014).

Cold recycling involves the use of reclaimed asphalt pavement (RAP) instead of traditional aggregates. The use of RAP in asphalt mixtures in high volumes not only alleviates the problem of waste accumulation but also reduces the need for new aggregates and bitumen production (Fríasa et al., 2012).

Given the environmental and economic benefits of emulsified cold recycled mixtures (ECRM)s, these mixtures can be regarded as a sustainable alternative for pavement maintenance. American society of civil engineers (ASCE) has recently developed some guidelines in this regard based on economic, environmental and social principal parameters (Cox, 2015).

In a study carried out by Turk et al., (2016), cold recycling was compared with traditional asphalt rehabilitation methods from an environmental perspective. Results showed the larger environmental impacts of traditional rehabilitation method in terms of global warming (1%), acidification (18%), abiotic fossil fuel source depletion (15%) and primary energy consumption (16%). They added that the cold recycling is sensitive to the use of cement, the production of which also involves high amounts of greenhouse

* Corresponding author.
E-mail addresses: a.modarres@nit.ac.ir, amirmodarres2003@yahoo.com (A. Modarres).

https://doi.org/10.1016/j.jclepro.2018.07.155
0959-6526/

Abbreviations

AASHTO	American association of state highways and transportation officials
AMD	Acid mine drainage
ANC	Acid neutralizing capacity
ASCE	American society of civil engineers
C1	Mixture containing 1% cement
C2	Mixture containing 2% cement
CK3CW3	Mixture containing 3% CKD and 3% CWA
CK6	Mixture containing 6% CKD
CKD	Cement kiln dust
CW	Coal waste
CW6	Mixture containing 6% CWA
CWA	Coal waste ash
C-A-H	Calcium aluminate hydrate
C-A-S-H	Calcium aluminosilicate hydrate
C-S-H	Calcium silicate hydrate
ECRM	Emulsified cold recycled mixture
EPA	Environmental protection agency
ESAL	Equivalent single axle load
GHG	Greenhouse gas
ITS	Indirect tensile strength
MQ	Marshall quotient
MTCLP	Modified toxicity characteristic leaching procedure
NA	No additive mixture
PAHs	Polycyclic aromatic hydrocarbons
RAP	Reclaimed asphalt pavement
TSR	Tensile strength ratio
VMA	Voids in mineral aggregates
XRD	X-ray diffraction
XRF	X-ray fluorescence spectrometry

gases (GHG)s emission (Turk et al., 2016).

In the cold recycling process, it is imperative to properly analyze the environmental properties of reclaimed materials so as to ensure that the mixture and its leachate will be free of potentially hazardous substances such as toxic compounds, dust particles with significant air pollution effects, etc. (Tabaković, 2013). Oil bitumen contains various types of hydrocarbons, and during its lifetime, come in contact with all sorts of chemicals produced by or released from vehicle exhaust, gasoline, lubricants and tires. The major chemical substances typically found in asphalts are heavy metals such as Cd, Cr, Cu, Ni, Pb, and Zn and polycyclic aromatic hydrocarbons (PAHs) (Legret et al., 2005).

Legret et al., 2005, investigated the leaching of heavy metals and PAHs from reclaimed asphalt. Their study showed higher initial concentrations of hydrocarbons and some PAHs in reclaimed asphalt than in traditional asphalt. This highlighted the necessity of performing environmental investigation on reclaimed materials to be reused in road construction projects (Legret et al., 2005). These tests may also be used for quality control purposes and to ensure that the materials to be used in road construction are adjusted and mixed in accordance with regulatory requirements (Miliutenko et al., 2013).

2. Use of cement kiln dust (CKD) and coal waste ash (CWA) in road construction and their environmental implications

ECRMs are typically susceptible to problems such as raveling, thermal cracking, rutting and low initial strength. One way to avoid these problems is to use additives and modifiers (Cross, 2000; Niazi and Jalili, 2009).

So far, researchers have recommended many types of additives to improve the initial properties of cold mixtures. Additives most commonly used for this purpose are ordinary Portland cement and lime (Martínez-Echevarría et al., 2012). However, sensitivity analyses of cold recycled mixtures have shown that using cement with high clinker content might have even much larger global warming impact than traditional rehabilitation methods (Turk et al., 2016).

Higher costs and environmental implications of cement and lime production processes have encouraged the use of waste additives in cold recycled mixtures.

At present, the cement industry is under increasing pressure to reduce its GHG emissions and solid byproducts in the form of cement kiln dust (CKD). CKD is a fine powder that is generated during the cement production process. At the end of cement production process, CKD is captured from the exhaust gases of flues and is collected in electrostatic baghouses or precipitators. The portion of CKD that contains significant amounts of volatile substances such as Na_2O and K_2O, or chlorine- and sulfur-containing compounds cannot be reused in the kiln and will be stored in stockpiles or deposed in landfills (Khanna, 2009).

As a general rule, CKD has about one-third of cementitious compounds present in ordinary Portland cement (Sreekrishnavilasam et al., 2007). The use of CKD in applications such as concrete production, soil stabilization, waste solidification, mine reclamation, pavement construction etc. has become an attractive alternative to its disposal.

According to the studies conducted by the US environmental protection agency (EPA), heavy metal contents of CKD rarely exceed the allowed limit. But X-ray diffraction (XRD) analysis has shown that CKD leachate contains very high concentrations of leachable potassium, sulfate, alkaline compounds, Cr and Mo (Kunal et al., 2012). Research has shown that the leachate of CKD-containing HMA has significantly lower heavy metal concentration than dry CKD. Thus, CKD can indeed be used in asphalt mixtures to achieve environmental goals such as reduced CKD deposit and reduced risk of air and water pollution (Kunal et al., 2012).

When used as a filler, CKD can improve Marshall stability, specific gravity, and uniaxial compressive strength of HMA. But the workability, porosity, and voids in mineral aggregates (VMA) decreased by increasing the CKD content (Ahmed et al., 2006). During a study, where CKD was used as filler in cold bituminous emulsion mixture, the results showed that CKD-containing mixtures had the same mechanical properties as the cold mixtures that contained limestone filler (Abdel-Wahed and Al Nageim, 2016).

Modarres et al., 2015 examined the durability of CKD-containing asphalt mixtures against freeze-thaw cycles using the indirect tensile strength (ITS) test and reported that the mixtures containing CKD filler had a higher resistance than the control mixture containing limestone filler (Modarres et al., 2015).

The waste materials with potential use in cold recycling include different pozzolans produced as byproducts in factories, mines, etc. One example of these materials is the coal waste (CW) that can be collected from the refuse dumps of coal washing plants. CW depots can be a major source of environmental problems. The environmental problems of coal mines are generally related to pyrite and iron-containing substances, which when exposed to water and/or air, rapidly oxidized and produce acidic waters. The resulting acid mine drainage (AMD), which has a low pH and contains high amounts of iron and SO_2 and variable amounts of toxic metals, is one of the most important causes of water contamination around