Cold Regions Science and Technology 137 (2017) 48–59

Contents lists available at ScienceDirect

Cold Regions Science and Technology

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

Durability properties of non-air entrained roller compacted concrete pavement containing coal waste ash in presence of de-icing salts

Seyed Alireza Mohammadi Rad, Amir Modarres *

Department of Civil Engineering, Babol Noshirvani University of Technology, Babol, Iran

ARTICLE INFO

Article history:
Received 17 October 2016
Received in revised form 15 February 2017
Accepted 18 February 2017
Available online 21 February 2017

Keywords:
Roller compacted concrete
Coal waste ash
Durability
De-icing salts

ABSTRACT

The aim of this study was to evaluate the durability properties of non-air entrained roller compacted concrete pavement (RCCP) containing coal waste ash (CWA) as partial replacement of cement in presence of de-icing salts. Four different mix combinations were used to prepare RCCP specimens. In control mix with no CWA, the cement content was fixed to 14% by mass of dry aggregates. In other mixes, cement was replaced with 2, 3 and 4% CWA (by mass of dry aggregates) named as C2, C3 and C4, respectively. Durability characteristics such as permeable void content, chloride ion penetration, de-icing salt surface scaling resistance and freeze-thaw resistance exposed to salt solution were evaluated. According to results, all studied RCCPs showed acceptable chloride ion penetration. By increasing CWA content up to 3%, surface scaling exposed to salt solution delayed approximately 5 cycles. In presence of salt solution, up to 180 freeze-thaw cycles, ultrasonic pulse velocity in control mix was slightly more than C2 and C3 mixes while at higher cycles than 180 the reverse was true. C4 mix revealed excellent resistance during initial 180 freeze-thaw cycles while its resistance drastically reduced in continue and showed critical behavior up to 300 cycles. Relative dynamic modulus of elasticity during 300 freeze-thaw cycles was almost the same for the control, C2 and C3 mixes. Conversely, C4 mix experienced more than 40% dynamic modulus reduction at the end of freeze-thaw test. The durability factor at the end of freeze-thaw test was satisfactory for the control, C2 and C3 mixes. Based on the results of durability tests, the optimum CWA content was determined as equal to 3%.

1. Introduction

Road pavements are special structures that continuously exposed to environmental factors. Therefore, in addition to strength properties, attention to durability characteristics of pavement materials is vital for long term performance of such structures. Environmental factors directly affect the durability of road pavements. For example, in cold climates the consecutive cycles of freezing and thawing along with the use of de-icing salts, accelerates the pavement deterioration (Valenza and Scherer, 2007; Wu et al., 2015).

Concrete devastations related to continuous freeze-thaw cycles and de-icing chemicals, can be appeared in form of surface scaling, cracking and disintegration of cement paste (Sutter et al., 2008). Surface scaling is one of the most common deteriorations caused by freezing and thawing of a thin layer of de-icing chemicals spread on the surface of concrete pavement. This distress is manifested by cutting small sheets and flake shaped pieces of surfaces (Valenza and Scherer, 2007).

Microstructural analysis of concrete samples after freeze-thaw cycles indicated the formation of Friedel's salt by chemical reaction between NaCl and $CaCl_2$ and calcium aluminate hydrates. It was observed that concrete damages were due to combined action of frost damage and formation of Friedel's salt (Wu et al., 2015). In order to reduce the premature deterioration of road infrastructures, numerous researches have been carried out to assess the durability of concrete in freeze-thaw and de-icing chemical attacks conditions. Effects of parameters such as water cement ratio and utilizing supplementary cementitious materials (SCMs) on frost resistance of concrete, were evaluated in numerous researches. Also, some general precautions such as air entraining admixture (AEA), antifreeze additives and lightweight aggregates have been introduced as effective ways used to prevent freeze-thaw damages (Ji-Liang et al., 2014; Ramezanianpour et al., 2014).

According to literature, using air entraining additives to create adequate air content in concrete, is essential to prevent surface scaling (Ji-Liang et al., 2014; Ramezanianpour et al., 2014; Valenza and Scherer, 2007; Van den Heede et al., 2013). Porous aggregates such as void-lightweight aggregates compared to the conventional types, are more durable during freeze-thaw conditions due to higher permeability

* Corresponding author.
E-mail address: a.modarres@nit.ac.ir (A. Modarres).

http://dx.doi.org/10.1016/j.coldregions.2017.02.006
0165-232X/

that water can easily escaped (Polat et al., 2010). Utilizing antifreeze additives such as calcium nitrate ($Ca(NO_3)_2$) and urea ($CO(NH_2)_2$), illustrated reduction of water absorption for all freeze-thaw cycles (Polat, 2016).

In order to minimize the surface scaling in non-air entrained concrete the water cement ratio is limited to 0.40–0.45% (Ji-Liang et al., 2014). By increasing the water cement ratio, resistance to freeze-thaw cycles and deicer chemicals will be dramatically reduced. Considering durability properties Sun et al. (2012), have recommended to minimize the water cement ratio and fly ash content to 0.42 and 30%, respectively (Sun et al., 2012). Simultaneous use of 10% waste glass sludge (obtained from glass plate processing factory) and 10% fly ash resulted in less chloride ion penetration, less surface scaling and more freeze-thaw resistance (Kim et al., 2014). Partial replacement of cement with tuffs and limestone, increased the water penetration depth in RCCP. Also, mixtures containing blended cement obtained higher corrosion resistance compared to other samples (Ramezanianpour et al., 2014). Incorporating reinforcement fibers showed enhancement in freezing and scaling resistance of concrete. Metal fibers were more effective than polypropylene ones. Also short fiber with flat end played better role than tall one with hooked end (Berkowski and Kazberuk, 2015). Utilizing polypropylene fiber was effective for obtaining satisfactory resistance against deicer salts (Deja, 2003).

Besides recommendations on additives and water cement ratio, air entraining is highly regarded to prevent frost damages. Non-air entrained specimens with blast furnace slag cements had lower resistance compared to conventional PCC. Between 5 and 6% entrained air, attained high resistance against deicer salts even at high water cement ratios (Deja, 2003). Van den Heede et al. (2013), studied the durability characteristics of PCC containing fly ash and 450 kg/m^3 total cementitious materials with water cement ratio of 0.35. They found that artificial air-entraining is necessary to minimize deicer salt scaling (Van den Heede et al., 2013). Crucial role of air entraining additives in preventing frost deteriorations was observed in Liu and Hansen (2016), research. High strength PCC with proper air entrained content, showed lower scaling compared to normal strength PCC. Furthermore, high strength PCC with reduced permeability, was prone to formation of internal cracks caused by hydraulic pressure due to continuous freezing (Liu and Hansen, 2016). Utilizing 5% silica fume or 1% air-entraining in PCC showed acceptable resistance against detrimental effects of deicing salts (Wu et al., 2015). Surface scaling decreased by increasing entrapped air content in PCC. For more than 3.8% air content, its advantages effects were not obvious (Ji-Liang et al., 2014). Durability properties of PCC in freezing condition with the existence of deicer, initially improved by increasing entrained air up to 4.8% while the reverse was true at higher air voids (Sun et al., 2012). Air-entraining reduced the water penetration depth in PCC specimens. Also, entrained air bubbles prevented bleeding and raveling and improved surface scaling resistance of concrete specimens. Mixtures containing entrained air bubbles and blended cement had the highest surface scaling resistance (Ramezanianpour et al., 2014).

Since concrete pavements are in direct contact with air and other environmental factors, their durability characteristics are more important than other concrete structures in both technical and safety viewpoints. Current laboratory research focused on the durability properties of roller compacted concrete pavement (RCCP) against detrimental effects of freezing and presence of de-icing salts. Roller compacted concrete (RCC) is a type of concrete mixture that extensively used as pavement materials. The use of RCCP has several advantages in road systems construction. Due to lower water cement ratios than PCCs, RCCPs are known as zero slump concretes that can be constructed and placed with the same equipment used to prepare asphalt pavements. Since RCCPs are relatively dry concretes, they can be opened to traffic within a short period of time (Brotman et al., 2007; Hossain and Ozyildirim, 2015; Luhr, 2004).

Limited researches have focused on durability properties of RCCs and especially RCCPs against the combined effects of de-icing salts and freeze-thaw cycles. Utilizing 20, 40 and 60% fly ash as partial replacement of cement, decreased the dynamic modulus of elasticity of RCC after freeze-thaw cycles. On the contrary, replacing a part of aggregates with fly ash (20, 40 and 60% by mass of cement), led to an increase in dynamic modulus of elasticity of RCC mixes after freeze-thaw conditions (Aghabaglou et al., 2013).

Pozolanic materials such as natural pozzolans, fly ash and silica fume generally enhanced the RCCP's consistency. Also, predominant scaling resistance of RCCP mixes, modified with silica fume obtained after exposing to de-icing salts (Nili and Zaheri, 2011). In early curing ages, RCCP control mixture without fly ash showed lowest chloride ion penetration. While, by increasing curing time, the RCCPs containing fly ash (20, 30, 40 and 50% by mass of cement) showed more chloride ion penetration resistance. The lowest chloride ion penetration obtained for 91-day RCCP containing 30% fly ash (Won et al., 2009).

Apart from above-mentioned studies, limited studies have been performed regarding the durability characteristics of RCCPs with the combining effects of freeze-thaw cycles and the presence of de-icing salts. In addition to conventional RCCP, the main theme of this research was to investigate the effect of using coal waste ash (CWA) as cement replacement. Current research is trying to pursue environmental approach by using waste materials, besides dealing with the technical aspects of durability of RCCPs.

Despite the crucial role of coal in energy supply, there are several environmental concerns regarding to use of this material. In process of extraction, preparation, quality enhancement and even after use as fuel in plant (due to large quantities of ash production), environmental damages are inevitable.

Based on the location and type of coal mine, several toxic metals could be detected in its leachate and its burning gases. However, in most cases the presence of toxic metals such as mercury and selenium has been reported in literature (U.S. Environmental Protection Agency, 2010). Around the most active coal washing plants, large quantities of wastes can be observed. These wastes often contain iron, sulfate-bearing material and pyrite. When pyrite or other toxic metals are exposed to the atmosphere or water, they will increase the risk of oxidation and production of acid mine drainage (AMD) (Akcil and Koldas, 2006; Moradzadeh et al., 2007). Due to low pH and high concentration of heavy metals and other toxic gases, AMD increases the risk of surface and groundwater and soil pollution (Akcil and Koldas, 2006).

The Alborz Markazi coal washing plant located in the north of Iran, is one of oldest coal mines of Iran with 557 million tons of probable reserves. At present, due to coal washing process, more than 2 million tons of coal waste dumps are available which leads to several environmental problems such AMD, surface and subsurface pollution and inappropriate view (Modarres et al., 2015; Shahhoseiny et al., 2013).

It has been proved that coal waste powder contains pozzolanic compounds and has the same properties as class F fly ashes (Modarres and Rahmanzadeh, 2014). 28-day PCC specimens containing coal bottom ash and fly ash, showed the same compressive, flexural and indirect tensile strength compared to control mixture. Based on the report, studied PCC mix were appropriate for applications such as foundation, sub-base and road pavements (Rafieizonooz et al., 2016). According to the literature, utilizing 5–10% CWA or 5% coal waste powder (CWP) as partial replacement of cement, resulted in the same mechanical properties compared to control mix (Hesami et al., 2016). The coal waste dumps which located around the coal washing plants lead to several environmental problems and using these materials in pavement construction is a way to get rid of such issues.

In this research durability properties of RCCP containing CWA were evaluated in freeze-thaw condition with the existence of de-icing salts. Permeable void content and chloride ion penetration resistance of RCCP specimens were evaluated. Deicer salt surface scaling resistance and freeze-thaw in exposure to de-icing salt solution were used to simulate the combining effects of cold weather and presence of deicer salts.