Journal of Cleaner Production 121 (2016) 1–18

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Review

A review of waste products utilized as supplements to Portland cement in concrete

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ARTICLE INFO

Article history:
Received 8 September 2015
Received in revised form
28 January 2016
Accepted 2 February 2016
Available online 11 February 2016

Keywords:
Waste
Portland cement
Concrete
Supplementary cementitious materials (SCM)
Beneficial use
Recycling

ABSTRACT

The amendment of concrete with waste products serves as an avenue to decrease the volume of wastes landfilled and to reduce the use of naturally mined materials, therefore, minimizing the footprint and impact that the construction industry has on the environment. This manuscript summarizes the current state of practice with regard to the use of waste products as supplementary cementitious materials (SCM) in portland cement concrete (PCC) and provides a summary of the comparatively sparse information on under-utilized waste materials such as: sugarcane bagasse ash, rice husk ash, waste wood biomass ash, and waste glass. The latter are all waste products that have the potential to be employed alongside traditional SCM, however much of the use to date has been done at the laboratory scale. This document will serve as a guide for the use of non-traditional waste SCM, to highlight areas likely requiring further refinement or research, and to indicate potential negative impacts from utilization of these products that might occur. The beneficial use of waste materials as SCM outside the United States has grown in recent years, mainly out of necessity; however, current research indicates that these materials typically provide a benefit when amending PCC and mortar.

Contents

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http://dx.doi.org/10.1016/j.jclepro.2016.02.013
0959-6526/© 2016 Published by Elsevier Ltd.

1. Introduction

In light of concerns pertaining to the sustainable use of natural resources and the adverse effects of improper waste disposal, the beneficial use of municipal and industrial byproducts is the subject of growing interest (Meyer, 2009). Incorporation of otherwise discarded materials into construction products for buildings, roads, and other infrastructure is one of the more commonly proposed beneficial use applications. In addition to reducing the volume of waste disposed of in landfills, this practice reduces the use of naturally mined materials, thus, reducing the footprint and impact of the construction industry on the natural environment. Potential byproduct end uses include construction fill (Arulrajah et al., 2014; Deng and Tikalsky, 2008; Rogbeck and Knutz, 1996) and concrete and pavement aggregate (Akbulut and Gürer, 2007; Akçaözoğlu et al., 2010; Bilir et al., 2015; Gencel et al., 2012; Ismail and Al-Hashmi, 2009; Marinković et al., 2010; Rao et al., 2007; Uygunoglu et al., 2012). However, from an environmental perspective, perhaps the most desired application is one where the target material replaces or supplements a binder in a concrete product (e.g., replacement of Portland cement (PC) in PC concrete). This reuse option is advantageous because of the greater economic value represented by cement replacement (Meyer, 2009), as well as the intrinsic environmental benefit resulting from more complete integration of the waste material into a solidified product (Van den Heede and De Belie, 2012).

PC concrete is the most widely used material for construction of built infrastructure on a global basis; and is primarily composed of mined materials which include: limestone, sand, and clay that are heated in a kiln to be processed for use. The manufacture of PC consumes a great deal of energy and results in a release of carbon dioxide; it was estimated that production of PC is responsible for approximately 5% of global carbon dioxide (CO_2) emissions, with a global mean value of 222 kg of carbon emitted per ton of PC produced (Cai et al., 2015; Supino et al., 2016; Worrrell et al., 2001). With a worldwide production of over four billion metric tons of cement in 2014 (Van Oss, 2014), the replacement of PC with municipal and industrial byproducts has the potential to significantly reduce negative impacts of construction (such as climate change) on the global environment. Alternative materials used to replace portions of PC within Portland cement concrete (PCC) are referred to as supplementary cementitious materials (SCM). Benefits of using SCM in concrete discussed herein include increased long-term strength, reduced permeability, and mitigation of the potential for deleterious reactions such as alkali-silica reactivity (ASR) or delayed ettringite formation (DEF) (Hewlett, 2006; Kosmatka et al., 2002; Mindess et al., 2003; Siddique, 2003). Both of these are deleterious, expansive chemical reactions which cause hardened concrete to crack. However, the potential drawbacks of using inappropriate materials to replace PC within PCC can be numerous and harmful to the integrity and serviceability of a structure. A number of waste materials have been successfully utilized as SCM, most notably coal fly ash and blast furnace slag (Kula et al., 2002; Özkan et al., 2007 Shi and Qian, 2000). Many other materials, however, have the potential to serve as a viable SCM, but their use is limited in part because of limited recognition of their availability and performance as SCM.

This paper provides a review of waste products utilized as SCM, their physical and chemical characteristics, their effect on the plastic and elastic properties of PCC as well as information with regard to production and utilization. The novelty of this document is that it provides a clear and concise summary of state-of-the-art published research involving SCM, which are industrial waste materials. Previous research has provided information on the benefits of utilizing "main stream" wastes used as SCM such as coal fly ash, granulated blast furnace slag, and silica fume (Celik