Journal of Building Engineering 5 (2016) 119–141

Contents lists available at ScienceDirect

Journal of Building Engineering

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

Cementitious materials and agricultural wastes as natural fine aggregate replacement in conventional mortar and concrete

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A R T I C L E I N F O

Article history:
Received 19 August 2015
Received in revised form
23 November 2015
Accepted 29 November 2015
Available online 2 December 2015

Keywords:
Cementitious materials
Agricultural wastes
Recycling
Fine aggregate
Fresh properties
Hardened strength
Durability

A B S T R A C T

In the last 15 years, the worldwide consumption of natural sand as fine aggregate in mortar/concrete production is very high and many developing countries have encountered some problems in the supply of natural sand in order to meet the increasing demands of construction development. In many countries there is a shortage of natural sand that is suitable for construction. On the other hand, disposal of wastes such as fly ash (FA), bottom ash (BA) and agricultural wastes can be considered as the major environmental challenges. This challenge continues to increase with the increase of these wastes. Therefore, studies have been carried out to find suitable solutions of the shortage of natural sand and the huge increasing in the wastes disposal. One logical option to solve this problem is employing these materials as a part of fine aggregate instead of natural one in mortar/concrete. This paper presents an overview of the previous studies carried out on the use of the previous wastes as a partial or full of natural fine aggregate replacement in traditional mortar/concrete mixtures based on Portland cement (PC). Other cementitious material such as ground basaltic pumice and metakaolin (MK), which can replace part or full of natural fine aggregate was also included. Fresh properties, hardened properties and durability of mortar/concrete containing these waste/cementitious materials as natural fine aggregate replacement have been reviewed.

Contents

Abbreviations: FA, fly ash; BA, bottom ash; PC, Portland cement; SS, steel slag; BOF, basic oxygen furnace; EAF, electric arc furnace; SF, silica fume; OPS, oil palm shell; OPBC, oil-palm-boiler clinker; PKS, oil palm kernel shell; RHA, rice husk ash; CA, corncob ash; OA, olive ash; WSA, wheat straw ash; SBA, sugarcane bagasse ash; MK, metakaolin; GBFS, granulate blast-furnace slag; CS, copper slag; SP, superplasticizer; W/c, water/cement; W/b, water/binder; HRWR, high range water reducer; RCPT, rapid chloride permeability test

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http://dx.doi.org/10.1016/j.jobe.2015.11.011
2352-7102/

1. Introduction

The worldwide consumption of natural sand as fine aggregate in mortar/concrete production is very high and several developing countries have met some strain in the supply of natural sand in order to meet the increasing demands of construction development. In many countries there is a shortage of natural fine aggregate which is suitable for construction. Natural sand is most common material which used as natural fine aggregate. In general, in the last 15 years, it has become clear that the availability of good quality of natural sand continues in decreasing [1]. The shortage of the resources of natural sand opened the door for using by-products and cementitious materials as a source of fine aggregate. Reuse of by-products as a partial or full replacement of natural fine aggregate in construction activities not only reduces the demand for extraction of natural raw materials, but also saves landfill space and reduce the consumption of natural resources.

Fly ash (FA) and bottom ash (BA) are residues from the combustion of coal. Coal ash is formed when coal is burned in boilers that generate steam for power generation and industrial applications. FA accounts about 80% of all the coal ash, whilst BA accounts about 20%. FA is captured in the chimney, whilst BA is collected from the bottom of the furnace from the coal fired power plant. The particles of FA are very fine, whereas BA has much larger particle size which is about the size of sand but more porous. The physical and chemical characteristics of FA or BA can vary greatly and will mainly depend on the combustion method and coal properties used at a particular power plant. High quantities of FA were found in the world. Around one billion tonne of FA is produced annually worldwide in coal-fired steam power plants [2]. Although FA can be used in high volume to replace Portland cement (PC) [3–6] or as a source of alkali-activated FA system [7], only a small part of this ash is used (20–30%); the rest is land filled-and surface-impounded, with potential risks of air pollution, contamination of water due to leeching [8]. Therefore, FA should not only be disposed of safely to prevent environmental pollution, but should be treated as a valuable resource.

About 20%, by volume, of the total combustion of coal is BA, depending on the type of boiler, dust collection system, burning temperature and the type of coal. Its particle is porous, irregular and coarser than that of FA, but its chemical composition is not much different [9]. About 45% of BA is used in transportation applications such as asphalt concrete aggregate, road base material, embankment or backfill material and structural fill [10]. Others used BA in concrete production as a part of binder material [11] or as a part of aggregate [12]. The remaining amount of this material is still damped in landfill sites caused environmental problems.

Although the uncertainty of the available references, the world steel industry has produced approximately 1.5 billion tonnes of steel in 2012 [13]. The generated waste slag is calculated between 10% and 20% of the raw materials used (according to oxide content, oxygen supply volume, the quality of metal or furnace efficiency), suggesting a huge amounts of wastes generated by these processes [14]. Steel slag (SS) is a by-product from either the conversion of iron to steel in a basic oxygen furnace (BOF), or the melting of scrap to make in an electric are furnace (EAF). It is the largest by-product from a minimill. The SS wastes are generated daily caused problems and hazardous for both the factories and the environment [15]. In the literatures, most of studies used SS as coarse aggregate in concrete and several of them concluded positive effect of SS on the mechanical properties [16–20]. Others used it in asphalt mixtures [21–25] or as a part of binder material [26–31], whilst there are limited studies which used it as fine aggregate.

Silica fume (SF) is a by-product waste produced by electric arc furnace during the production of metallic silicon or ferrosilicon alloys. The amounts of production of SF as by-product especially in industrial counties have reached alarming proportions. It was estimated that the global output of SF, at almost, between 1 and 1.5 million tonnes annually [32]. SF is also known as silica dust, micro silica, volatilzed silica or condensed silica fume composed primarily of pure silica in non-crystalline form. Its particle size is usually $< 1\ \mu m$, surface area is ranging from 13,000 to 30,000 m^2/kg, specific gravity is around 2.22 and its bulk density (as produced) are in the range of 130–430 kg/m^3 [33]. Although there are several technical advantages of using SF as mineral admixtures in matrix based on PC [34–37] or in matrix based on alkali activation of materials [7,38,39], in most cases most of SF has to be disposed off into landfill. This has significant hazardous environmental impact as it causes air pollution or groundwater pollution. Employing SF as a part of natural sand may help to solve this problem.

Oil palm shell (OPS), oil-palm-boiler clinker (OPBC), oil palm kernel shell (PKS), rice husk ash (RHA), corncob ash (CA), wheat straw ash (WSA), olive ash (OA) and sugarcane bagasse ash (SBA) are agricultural by-products. There are many tonnes of these materials are generated each year. Although some of these materials can be used as animals food or fuel in biomass power plants or in boilers of various industrial sectors to produce steam, a lot of these materials are still disposed off into landfill or burnt caused environmental problems. The utilization of these agriculture waste materials in concrete reduces the environmental problems and