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Review

Recycling combustion ash for sustainable cement production: A critical review with data-mining and time-series predictive models

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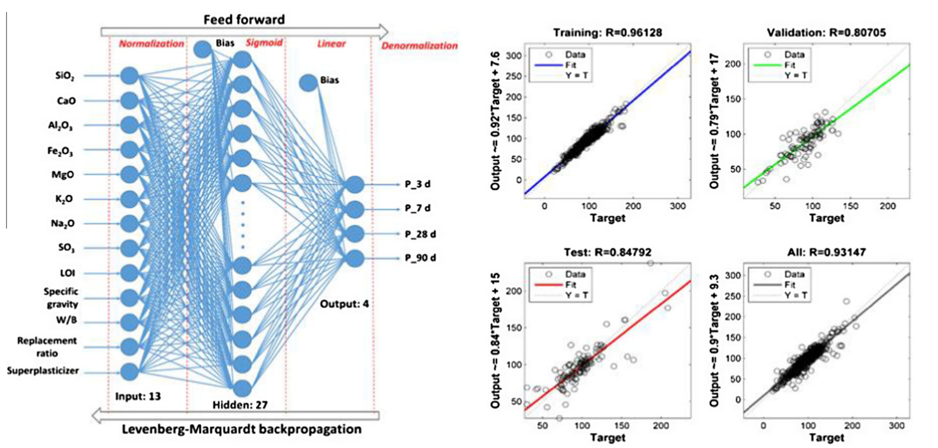
HIGHLIGHTS

- Critically reviewed the recent research progress on various ashes as pozzolans.
- Created data-mining artificial neural network to predicting pozzolanic activity.
- Quantified the effect of cement curing on pozzolans by a time-series model.
- Accurately forecast the pozzolanic activity in 3–90 d curing (R^2 = 0.8479–0.9914).
- Recommended this model as a rapid estimator of pozzolanic activity before testing.

GRAPHICAL ABSTRACT



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ABSTRACT

Combustion is a complex process that produces energy as the goal and ashes as by-products. The ash of coal, biomass and solid waste combustion can be used as pozzolans in blended cement due to the similarity of their physiochemical properties to conventional pozzolans (e.g. silica fume). This strategy effectively recycles pozzolanic-active combustion ash and replaces a significant proportion of Portland cement, which potentially reduces the greenhouse gas (GHG) emissions from cement production. However, cement producers wishing to substitute pozzolanic-active ash for conventional pozzolans lack information on the pozzolanic activity (PA) of ash from diverse combustible materials. A data-mining model that can extract key information for predicting the PA of combustion ash is envisioned as a screening tool to assess the pozzolanic potential of candidate combustible materials prior to experimental work. Hence, the objectives of this chapter are, 1) to critically review the recent research progress in using various combustion ashes as pozzolans, including the mechanism of the pozzolanic reaction, sources of eligible materials, and methods of PA improvement, 2) to create a data-mining artificial neural network (ANN) model for PA prediction built upon data reported in the scientific literature from 1998 to 2015, and 3) to describe the effect of cement curing period on PA, based on a time-series model. The ANN and time-series models developed in this study can accurately forecast

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the PA of combustion ashes during 3–90 d curing (R^2 = 0.8479–0.9914). We recommend these screening tools as rapid indicators of the pozzolanic potential of combustion ash prior to undertaking strength tests and other experimental testing.

Contents

1. Introduction

The Portland cement industry relies upon the pozzolanic reaction to achieve the desired binding and structural strength in cement products at a lower economic cost than using Portland cement alone. A pozzolan is a siliceous or siliceous-aluminous material with virtually no cementitious function. In the presence of water, it reacts with $Ca(OH)_2$, hereafter referred to as CH, to generate $(CaO)_x{\cdot}(SiO_2)_y{\cdot}(H_2O)_z$, the C-S-H complex that is the key contributor to concrete strength [22,84]. Supplemental C-S-H formation during cement hydration due to the pozzolanic reaction can improve concrete properties such as strength and durability [132]. Yet, the cement—pozzolan—water mixture is a complex system, consisting of many physicochemical processes that are influenced by temperature, mixing proportion, pozzolan reactivity, pozzolan particle size and other factors. The challenge is to choose a suitable and economically feasible pozzolan with the right physicochemical characteristics to assure the final quality of concrete.

Up to 50% of the Portland cement can be replaced by a pozzolan in a blended cement without any adverse impact on concrete performance [50,71]. Blending cement with silica-rich pozzolans like volcanic ash, diatomaceous earth and silica fume is a practice dating back to antiquity, based on structures built more than 2000 years ago by Greek and Roman civilizations [67]. Solid wastes such as combustion ash and catalyst residue can be used as a pozzolan if they possess physiochemical properties akin to conventional pozzolans (e.g. silica fume). An eligible pozzolan should be rich in siliceous or siliceous-aluminous compounds and have a fine particle size (<45 μm) [114]. This strategy effectively recycles these pozzolanic-active resources and reduces the amount of Portland cement needed to make strong and durable concrete, which potentially reduces the greenhouse gas (GHG) emissions from cement production [61,66]. Considering these environmental benefits in the context of sustainable cement production, many researchers have tested the pozzolanic activity (PA) of various solid wastes and reported their findings in the scientific literature, leading to more than 1612 publications on this topic in the Web of Science from 2005 to 2014. On the other hand, there are few papers that synthesize, critically analyze and discuss the findings to date. If solid wastes could be recycled as pozzolans without adverse impact on cement properties, these abundant wastes that costs little or nothing can lessen the demand for Portland cement, thus helping cement industry reduce its greenhouse gas (GHG) emissions. Therefore, a review study is indispensable to comprehensively understand the potential for recycling of solid waste as pozzolan.

The sizable database of experimental studies that evaluated the pozzolanic activity (PA) of diverse solid wastes can be used to develop a data-mining model that predicts the PA of these materials. The advantage of a data-mining model is that trends can be analyzed and generalizations made, giving the cement industry a robust screening tool to assess the pozzolanic potential of a waste material before undertaking experimental work. An artificial neural network (ANN) is an appropriate predictive tool for this purpose because ANN is a high-level data-mining algorithm that simulates