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Review

Supplementary cementitious materials origin from agricultural wastes – A review

Evi Aprianti [a,*], Payam Shafigh [b], Syamsul Bahri [b], Javad Nodeh Farahani [b]

[a] Department of Building Surveying, Faculty of Built Environment, University of Malaya, Malaysia
[b] Department of Civil Engineering, Faculty of Engineering, University of Malaya, Malaysia

HIGHLIGHTS

- Potential uses of agricultural wastes as cementitious material were reviewed.
- Ashes from agricultural wastes have high silica content.
- The use of RHA is limited due to the porosity nature of RHA particles.
- POFA has good potential to be used as cementitious material in cement based materials.

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ABSTRACT

Concrete is heavily used as a construction material in modern society. With the growth in urbanization and industrialization, the demand for concrete is increasing day by-days. Therefore, raw materials and natural resources are required in large quantities for concrete production worldwide. At the same time, a considerable quantity of agricultural waste and other types of solid material disposal are posing serious environmental issues. To minimize and reduce the negative impact of the concrete industry through the explosive usage of raw materials, the use of agricultural wastes as supplementary cementitious materials, the source of which are both reliable and suitable for alternative preventive solutions promotes the environmental sustainability of the industry. This paper reviews the possible use of agricultural wastes as a supplementary cementitious material in the production of concrete. It aims to exhibit the idea of utilizing these wastes by elaborating upon their engineering, physical and chemical properties. This provides a summary of the existing knowledge about the successful use of agricultural wastes such as rice husk ash, palm oil fuel ash, sugar cane bagasse ash, wood waste ash, bamboo leaf ash, and corn cob ash in the concrete industry.

Contents

* Corresponding author. Tel.: +60 1114247118; fax: +60 379675713.
E-mail addresses: eviaprianti93@siswa.um.edu.my, eviaprianti93@yahoo.com (E. Aprianti).

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1. Introduction

Today, concrete has become the most commonly used building material in the construction industry. The other important characteristics of concrete, besides its strength, are its ability to be easily moulded into any form, it is an engineered material that can meet almost any desired specification, and it also adaptable, incombustible, affordable and easily obtained. The great advantage of concrete is its excellent mechanical and physical characteristics, if properly designed and manufactured. Currently, concrete is extensively used with more than 10 billion tons produced annually in modern industrial society [1]. It has been estimated that by 2050, the rate of the world's population will grow substantially from 1.5 to 9 billion, and, thus, will cause an increase in the demand for energy, housing, food and clothing as well as for concrete, which is forecast to increase to approximately 18 billion tons annually by 2050 [2].

Unfortunately, a considerable quantity of concrete is being produced, the effect of which is contrary to its benefits. In the last 100 years, the concrete industry has had an enormous effect on the environmental appearances. In addition, CO_2 emissions are caused during the manufacturing process with a large volume of raw materials required to produce the billions of tons of concrete worldwide each year. The cement industry alone is estimated to be responsible for about 7% of all the CO_2 generated worldwide [3]. It has been found that every ton of Portland cement produced releases approximately one ton of CO_2 into the atmosphere. In addition, during the production of cement and concrete, issues like carbon dioxide emissions, along with the use of energy and aggregate consumption in great amounts, the demolition waste of concrete, and filler requirements, contribute to the common environmental impact that concrete has making it a non-friendly that is unsuitable for sustainable development.

Several studies have focused on finding alternatives that can be used as replacement to cement, such as, the disposable and less valuable wastes from industry and agriculture, whose potential benefits can be realized through recycling, reuse and renewing programmes. Hence, researchers have been investigating the effectiveness, efficiency and availability of waste materials that are pozzolanic in nature as a cement replacement. The required materials should be a by-product from an-original source that is rich in silicon (Si) and aluminium (Al). The framework for utilizing industrial waste material for building applications has a successful history, which includes fly ash, slag, and silica fume. Consequently, land filled waste materials that are normally disposed of and land filled are now deemed to be valuable for enhancing the desired properties of concrete.

Previous studies showed that some agro-waste materials could be used as a cement replacement in cement based materials. The utilization of agricultural waste can provide the break-through needed to make the industry more environmentally friendly and sustainable. The purpose of this paper is to clearly describe and briefly introduce waste materials from agricultural commodities that have been well managed and successfully used as supplementary cementitious materials (SCM) for the manufacture of concrete. The relationships among concrete made using these types of waste materials, environmentally friendly concrete, and green building rating systems are also discussed. Mutual recognition of these materials, and their usage in concrete by both civil engineers and agricultural engineers, would pave the way for other potential uses of solid waste materials in the construction industry, as well as certain other industries. It will also lead to a more environmentally sustainable concrete industry.

2. Supplementary cementitious material (SCM)

A substantial quantity of waste materials are produced globally as by-products from different sectors, such as industrial, agricultural, and wastes from rural and urban society. These waste materials, if not deposited safely, it may be hazardous. The type and amount of sewage produced increases with the growth in population. These wastes remain in the environment for a longer duration since they are unused. The waste disposal crisis has arisen due to the formation of decomposed waste materials. The solution to this crisis lies in the recycling of wastes into useful products. Research into the innovative uses of waste materials is continuously advancing. Waste and by-product materials, such as fly ash, silica fume, ground granulated blast slag, rice husk ash, and palm oil fuel ash have been successfully used in concrete for decades [4–8]. The successful usage as a partial or whole replacement of Portland cement, contributes to the resolution of the landfill problem and reduction in the cost of building materials, provides a satisfactory solution to the environmental issues and problems associated with waste management, saves energy, and helps to protect the environment from pollution. Agricultural wastes, such as rice husk ash, wheat straw ash, and sugarcane bagasse ash, hazel nutshell ash which constitute pozzolanic materials can be used as a replacement for cement.

Today, supplementary cementing materials are widely used as pozzolanic materials (create extra strength by pozzolanic reaction) in high-strength concrete, reduce permeability and improve the durability of the concrete. Many types of pozzolans are used globally, and are commonly used as an addition or replacement for Portland cement in concrete. It is well known that pozzolanic concrete contributes to the compressive strength in two ways: as the filler effect and the pozzolanic reaction. Thus, the pozzolanic material will reduce the demand or usage of cement at that time. A pozzolan comprises siliceous materials, and when combined with calcium hydroxide, exhibits cementitious properties depending on the constituents of the pozzolan. On the other hand, the "high early strength" concrete can be produced by the highly reactive silica in pozzolans. The basis of the pozzolanic reaction is a simple acid-based reaction between calcium hydroxide, also known as Portlandite ($Ca(OH)_2$) and silicic acid ($Si(OH)_4$). This reaction is represented as follows:

$$Ca(OH)_2 + (Si(OH)_4) \rightarrow Ca_2 + +H_2SiO_4^{2-} + 2H_2O \\ \rightarrow CaH_2SiO_4 \cdot 2H_2O$$

And is the same as the abbreviated notation below:

$$CH + SH \rightarrow CSH\tilde{C}{-}S{-}H$$

As the density of CSH is lower than that of Portlandite and pure silica, a consequence of this reaction is a swelling of the reaction products. This reaction, which is also known as alkali–silica reaction may occur over time in concrete between the alkaline cement pore water and poorly-crystalline silica aggregates.