Construction and Building Materials 159 (2018) 567–577

Contents lists available at ScienceDirect

Construction and Building Materials

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

An overview and experimental study on hybrid binders containing date palm ash, fly ash, OPC and activator composites

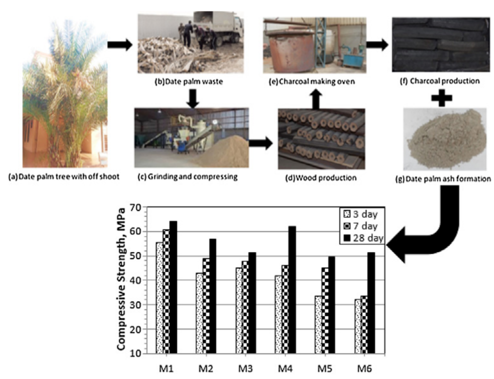
Walid Al-Kutti [a], Muhammad Nasir [a,b,*], Megat Azmi Megat Johari [b], A. B. M. Saiful Islam [a], Abdullah A. Manda [c], Nawaf I. Blaisi [d]

[a] Department of Civil and Construction Engineering, College of Engineering, Imam Abdulrahman Bin Faisal University, Dammam 31451, Saudi Arabia
[b] School of Civil Engineering, Universiti Sains Malaysia, Nibong Tebal 14300, Pulau Penang, Malaysia
[c] Department of Basic Sciences, College of Engineering, Imam Abdulrahman Bin Faisal University, Dammam 31451, Saudi Arabia
[d] Department of Environmental Engineering, College of Engineering, Imam Abdulrahman Bin Faisal University, Dammam 31451, Saudi Arabia

HIGHLIGHTS

- Overview on CO_2 emission, alternate cement approaches and date palm waste is presented.
- Binary and ternary hybrid blend were prepared by partially replacing OPC with DPA, GDPA, FA and NaOH.
- Flow, compressive strength, XRD, TGA, surface area and pore volume were evaluated.
- Non-hybrid ternary blend performed better and recommendations for hybrid binders' efficiency is made.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 21 September 2017
Received in revised form 1 November 2017
Accepted 7 November 2017

Keywords:
Date palm ash (DPA)
Fly ash (FA)
Hybrid binder
Alkaline activation
Strength
Microstructure

ABSTRACT

Global warming due to high greenhouse gasses emission coupled with excessive energy involved in concrete manufacturing process is indeed an alarming threat. To overcome the problem, numerous researches have been carried out to partially replace ordinary Portland cement (OPC) with supplementary cementitious materials (SCMs) that includes agricultural or industrial solid wastes, development of alternative binder known as geopolymer concrete made of one or more pure SCMs using alkaline activators and elevated temperature curing or by development of hybrid cement system that incorporates alkaline activation of OPC-based SCMs. This study aims to: (1) carry out an overview on: CO_2 emission by construction industry; alternate cement systems such as partial replacement, geopolymers and most importantly hybrid binders; as well as identification of date palm ash (DPA) as a potential waste material and (2) develop novel hybrid alkali activated binders with a combination of agro-industrial waste to form binary and ternary mortar binders cured under water up to 28-days. The utilized SCMs include fly ash (FA), ground date palm ash (GDPA) i.e. alkali activated or raw DPA i.e. non-activated. These hybrid and non-hybrid binders were compared through physical properties such as strength and workability along with

* Corresponding author at: School of Civil Engineering, Universiti Sains Malaysia, Nibong Tebal 14300, Pulau Penang, Malaysia.

E-mail addresses: wasalem@iau.edu.sa (W. Al-Kutti), nasir@student.usm.my, mnmuhammad@iau.edu.sa (M. Nasir), cemamj@usm.my (M.A. Megat Johari), asislam@iau.edu.sa (A. B. M. Saiful Islam), aamanda@iau.edu.sa (A.A. Manda), niblaisi@uod.edu.sa (N.I. Blaisi).

https://doi.org/10.1016/j.conbuildmat.2017.11.017
0950-0618/

microstructural properties by hydration products and pore volume. X-ray diffraction (XRD) technique was employed to get the mineral composition; phase decomposition of unreacted water, C-S-H/C-A-S-H gel and $Ca(OH)_2$ had been studied by Thermogravimetric analysis (TGA) while nitrogen adsorption test determined surface area of particles as well as pore volume of the paste. The results revealed potential use of DPA as a strong and sustainable material in ternary blend with FA and OPC in conventional non-hybrid binder that can efficiently maximize clinker replacement without energy utilization in alkaline activation.

1. Introduction

Strict environmental legislations are being imposed by the global authorities, that are also applicable to concrete industries having major branches of cement manufacturing plants, ready-mix plants and pre-cast concrete plants, to cope with the alarming threat of global warming, climatic changes and ozone layer depletion due to high greenhouse gasses emission and excessive energy involved in its manufacturing process [1,2]. The boom of concrete construction is worldwide growing exponentially resulting in estimated concrete consumption per capita of about 1 m^3 which uses a huge amount of cement, a primary construction material [3]. Globally, cement plants are responsible for about 3.5% [4] to 5% [5] of total anthropogenic carbon dioxide (CO_2) discharge with an intensity of 222 kg/ton of cement production [6]. It is further reported that cement industries are estimated to discharge up to 1.5 billion tons per year of CO_2 into the atmosphere [7] and each year it will remain increasing at the rate of almost 6% from 1988 to 2015 [8]. Moreover, it is estimated that production of every ton of traditional cement emits nearly same quantity of CO_2 into the atmosphere among which amount of CO_2 through combustion of fossil fuel in the kiln operation, production process and the transportation of cement accounts for 40%, 50% and 10%, respectively [9]. In fact, chemical and fuel burning process in cement manufacturing emits 50% and 40% of CO_2, respectively into the atmosphere [5]. It is reported that addition of 30% FA as ordinary Portland cement (OPC) replacement can reduce 30% of CO_2 emission [10]. According to the US Portland Cement Association (PCA) [11], different cement type manufacturing of each ton releases approximate CO_2 as follows: (a) Ordinary Portland cement – 1.02 tons/ton, (b) Fly ash-based cement – 0.014 ton/ton, (c) Geo-polymer cement by slag production – 0.31 tons/ton and (d) Geo-polymer cement thru by-product of slag = 0.21 ton/ton.

In this regard numerous researches have been carried out by concrete technologists and they started sustainable construction practice in these three common ways: (1) partially replacing OPC with one or more supplementary cementitious materials (SCMs) that includes agro-industrial solid wastes such as palm oil fuel ash (POFA), rice husk ash (RHA), date palm ash (DPA), fly ash (FA), natural pozzolan (NP), silica fume (SF), ground granulated blast furnace slag (GGBFS), superpozz (SP) and metakaolin (MK); (2) developing alternative binder known as geopolymer concrete that may made of one or more SCMs using alkaline activators and require elevated temperature curing; (3) developing hybrid cement binder that requires partial replacement of SCMs to OPC along with alkaline activation. There are other techniques being also adopted for minimizing the CO_2 emission by concrete industries such as capturing CO_2, use of alternate fuel source or modifying process of clinker manufacturing at cement plant, however, substitution of clinker by alternate SCMs is the most effective and economical solutions that can be easily applicable to the ready-mix plant [3,12].

Utilizing the SCMs as partial replacement has been continuously studied since last 3 decades due to its economical, ecological and technical benefits. As these are waste products that requires solid stockpiles and landfill, recycling them in concrete results in minimizing cost of construction as well as reduction in ecological imbalance. Technically, they are proven to produce more or less same concrete resulted thru neat OPC. Several researches have been done to find out optimum dosage of each SCMs to be partially mixed with OPC, effects on mix design and exposure conditions. For instance, Shamshad et al. [13] proposed compliance criteria for 100% OPC, 7.5% SF and 20% FA concrete by varying cementitious material content and w/cm ratio. The results of compressive strength and durability properties of SF cement concrete was found superior. ACI committee 305 specifies fresh concrete temperature limit of 35 °C while Nasir et al. [14,15] recently studied the performance of plain and blended cement concretes cast at in-situ temperature of 25–45 °C. They found that compared to neat OPC, partial replacement of SCMs including 10% SP, 30% FA, 70% GGBFS, 7% SF and 20% NP results better at higher temperature. A review on waste products used as SCMs to replace OPC concluded that some SCMs like FA, SF and GGBFS have already proven advantageous. However, there is a growing demand for identifying underutilized waste product and to partially incorporate with or to replace OPC that may potentially serve for the benefits of built infrastructure and the environment [16].

Incorporation of SCMs as an alternative alkaline activated binder (AAB) also known as geopolymer has been continuously gaining popularity since last two decades as it is 100% OPC free. The term "geopolymer" was first introduced by Davidovits in 1999 [17] and AAB have been developed by incorporating source materials which are chemically inorganic in nature and rich in silica (Si) and alumina (Al) [18]. However, the relevant research on this topic was started during late 1930s by Feret [19] and Purdon [20]. Recently, Hossain et al. [21] reviewed 92 papers of last decade focusing on the durability of concrete and mortar prepared with alkali-activated pozzolanic binder. They concluded that fly ash (FA), blast furnace slag (BFS), metakaolin (MK), rice husk ash (RHA) and palm oil fuel ash (POFA) has been extensively studied (both individually or blending with different activators and concentrations) to improve various properties of binder as compared to traditional cement specimens that enabled lowering disposal problem associated with waste products, reduction in traditional cement consumption, minimizing overall construction cost and decreasing CO_2 discharge. Pacheco-Torgal et al. [22] reviewed 70 research papers concerning durability aspect of alkali-activated binders and discussed its advantages and disadvantages based on the test properties that includes: acid attack, alkali–silica reaction, reinforcement corrosion, resistance to elevated temperature, fire and freeze–thaw and efflorescence. Several researchers have investigated effect of alkaline activation of various 100% SCMs or their blends, such as with FA [23], with NP [24], with GGBFS [25], with MK [26], with RHA [27] and with POFA [28]. Among these SCMs, FA is most widely used source material owing to its availability in abundance, more economical and high potential for geopolymer development [29].

An advanced innovative approach being recently researched is hybrid cement which can be developed by combining alkaline