Journal of Cleaner Production 161 (2017) 477–492

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Performance evaluation and some durability characteristics of environmental friendly palm oil clinker based geopolymer concrete

S.M. Alamgir Kabir, U. Johnson Alengaram*, Mohd Zamin Jumaat, Sumiani Yusoff, Afia Sharmin, Iftekhair Ibnul Bashar

Centre for Innovative Construction Technology (CICT), Department of Civil Engineering, Faculty of Engineering, University of Malaya, 50603, Kuala Lumpur, Malaysia

ARTICLE INFO

Article history:
Received 3 January 2017
Received in revised form
9 April 2017
Accepted 1 May 2017
Available online 19 May 2017

Keywords:
Palm oil fuel ash
Metakaolin
Ground granulated blast furnace slag
Palm oil clinker
Oil palm shell
Lightweight structural geopolymer concrete

ABSTRACT

Huge demand for concrete due to industrialization and urbanization has resulted in the depletion of natural resources and led to an ecological imbalance. Hence, this research focuses on alternative materials, including the utilization of waste materials as a replacement for binders and conventional aggregates. Palm oil fuel ash (POFA), ground granulated blast furnace slag (GGBS) and metakaolin (MK) were used as binders; while palm oil clinker (POC) and oil palm shell (OPS) used as coarse aggregate in producing geopolymer concrete. Seven concrete mixtures were designed with varying coarse aggregate contents to develop eco-friendly geopolymer concrete while other parameters were kept constant. The mechanical properties and some durability characteristics of lightweight geopolymer concrete were investigated and reported. The highest compressive strength achieved was 41.5 MPa at 28 days where 100% POC (9–14 mm) was used as coarse aggregate. POC in geopolymer concrete improves the compressive toughness compared to OPS geopolymer concrete because the porous POC aggregate increased the stiffness and improved the bond with mortar in concrete as the infilling effect of mortar into the pores strengthens the bond and enhances the crack growth resistance. Geopolymer concrete has lower capillary sorptivity, the usage of magnesium sulphate solution for sulphate resistance test showed negligible impact on geopolymer concrete due to the intrinsic nature of alumino silicate gels in geopolymeric materials. The results show that by utilizing POC and OPS structural grade lightweight geopolymer concrete can be produced.

1. Introduction

The construction industry is the largest consumer of natural resources; where the most commonly used construction material is concrete. The use of Ordinary Portland cement (OPC) has resulted in huge volume of carbon dioxide (CO_2) emission which accounts to about 0.6 ton from the production of 1 ton of cement (Yunsheng et al., 2007). Approximately 5% of global CO_2 emissions is attributed to cement industry (Lawrence, 1998).

The growing concern regarding the ecological consequences of dumping wastes has escorted researchers to study the use of wastes as possible replacement construction materials (Khale and Chaudhary, 2007). Huge research efforts have been carried on in the last few decades and reveal few solutions to mitigate the CO_2 emission; one such solution is the development and use of geopolymer concrete through the utilisation of wastes and industrial by-products (Kabir et al., 2015; Nuaklong et al., 2016; Perná and Hanzlíček, 2016; Sharmin et al., 2015). Davidovits (2008) was the pioneer in introducing the term known as 'geopolymer'. Geopolymers are reported to be more sustainable compared to Portland cement, in provisions of reduced production energy necessity, lower CO_2 emissions (Li et al., 2010). The alternative cementitious binder termed as 'geopolymer' derived from fly ash (FA), palm oil fuel ash (POFA), ground granulated blast furnace slag (GGBS) and metakaolin (MK) and these binders were used as whole replacement for OPC.

Malaysia is the second largest palm oil producing country in the world. There are almost 200 palm oil mills operating in Malaysia, which generate about 100 tons of POFA annually. This material has no market value and is simply dumped into ponds/lagoons which causes environmental pollution (Tangchirapat et al., 2007). Recent

* Corresponding author.
E-mail address: johnson@um.edu.my (U.J. Alengaram).

http://dx.doi.org/10.1016/j.jclepro.2017.05.002

researches (Islam et al., 2016; Mannan and Ganapathy, 2002; Rahman et al., 2014) focussed on the development of sustainable concrete using POFA and related waste materials from the palm oil industry.

The addition of GGBS in geopolymer concrete improved the pore structure quality of hardened geopolymeric matrix. Zhang (2003) found the 28-day compressive and flexural strengths of 75 MPa and 10 MPa, respectively in geopolymer concrete when 50% GGBS was replaced by MK.

The exploitation of river sand endangers the stability of riverbanks and creates environmental problems, such as flooding and the reduction of ground water level. Bashar et al. (2014) suggested the use of alternative materials for river sand, such as manufactured sand (M-sand), industrial by-products (some forms of slag, bottom ash), and recycled aggregates. Among these, the use of manufactured sand is gaining momentum (Nanthagopalan and Santhanam, 2011). The shape and texture of M-sand lead to improved strength due to better interlocking between the particles (Islam et al., 2014).

Designers look for solutions to reduce the self-weight of a structure which in turn could bring down the overall cost of construction. According to Euro code 2 Part 1-1, the density of structural lightweight concretes (LWC) is less than 2200 kg/m^3 and that of normal weight concrete varies between 2300 and 2500 kg/m^3 (Clarke, 2002). The typical method for constructing structural LWC is by incorporating light weight aggregate (LWA), which can be replaced either wholly or partially with conventional aggregates (Boyd et al., 2006). Thus, the use of lightweight LWA in the development of structural LWC is crucial.

Malaysia generates about 4.0 million tonnes oil palm shell (OPS) and a huge amount of palm oil clinker (POC) as waste materials (Ahmmad et al., 2014). Both POC and OPS have been used as LWA and based on the studies it was shown that both OPS and POC can be utilized as LWA for making structural LWC with compressive strength ranging from 17–54 MPa. This is the range of normal strength to high strength of LWC (Ahmmad et al., 2014).

The strength and density of POC fulfil the characteristics of the structural lightweight concrete (Beshr et al., 2003). OPS are considered as one of the prospective coarse aggregates in the improvement of LWC and it was used in the development of lightweight oil palm shell geopolymer concrete (OPSGC) (Islam et al., 2015); one of the salient features of the OPS concrete is its density is about 20–25% lower than normal weight concrete.

The use of POC and OPS as an alternative to the conventional coarse aggregate could reduce the cost of construction as well as a overwhelm burden to environmental ill impact. However, numerous researches have been carried out in different aspects and designs to utilize POC, OPS and POFA as construction materials and a little success have been addressed by application in real construction (The Centre for Innovative Construction Technology, 2016). The physical properties like high water absorption rate of OPS and POC, porosity in POC, possibility of degradation of OPS fibre after long period, inconsistent proportion of chemical compounds and fineness of POFA generated in various batch of production have limited the application in real construction. Researchers have proposed different techniques to be applied in different types of concrete production using these waste materials (Aslam et al., 2015; Islam et al., 2016; Mo et al., 2015b; Rahman et al., 2014; Shafigh et al., 2014). However, the mechanical and durability impact is a vital question for each type of concrete material and clear understanding has to be obtained before applying the practical development.

The POC is a pozzolanic aggregate, which has a potential to have a good bond in geopolymer matrix due to its characteristics consisting of alumina-siliceous compound. Therefore, a geopolymer binding matrix using tertiary pozzolans of GGBS, POFA and MK have been designed in this research to develop a geopolymer concrete containing POC and OPS as coarse aggregate and M-sand as fine aggregate as whole replacement for conventional mining sand.

The variable studied includes different sizes and percentages of POC as a replacement for OPS coarse aggregate. A total of seven mixes were prepared including one control mix contained crushed granite as coarse aggregate and tested for mechanical properties such as compressive strength, splitting tensile strength, flexural strength and modulus of elasticity. In addition, the compressive toughness behaviour and some durability characteristics of the concrete are also investigated.

Table 1
Chemical composition (%) of binders (MK, GGBS, POFA) by X-ray Fluorescence (XRF) analysis.

Chemical composition	MK	GGBS	POFA
CaO	0.04	45.83	4.34
SiO_2	52.68	32.52	63.41
Al_2O_3	42.42	13.7	5.55
MgO	0.12	3.27	3.74
Na_2O	0.07	0.25	0.16
SO_3	0.05	1.8	0.91
P_2O_5	0.4	0.04	3.78
K_2O	0.34	0.48	6.33
TiO_2	1.46	0.73	0.33
MnO	0.08	0.35	0.17
Fe_2O_3	2.01	0.76	4.19
SrO	0.03	0.08	0.02
Cl	–	0.02	0.45
CuO	–	–	6.54
LOI	–	0.6	6.2

2. Materials and methods

2.1. Binders

POFA is a waste material obtained from palm oil mill boilers by the burning of palm oil shell and husk at a temperature of 800 °C. However, this ash has pozzolanic characteristics that play a vital act in making durable and strong concrete by the replacement of cement. Raw POFA was collected from palm oil industry, Malaysia.

GGBS was used as one of the source materials to produce cement-less binder. GGBS develops its own hydraulic reaction when mixed with water. The combination of calcium, silicates and alumina comprising about 90% of GGBS shows that it satisfies the requirements of a pozzolanic material.

MK is an industrial by-product material, it has important potential in the improvement of concrete composites and it is an extremely reactive pozzolanic admixture. MK is manufactured from a natural geological mineral. The chemical composition and the physical properties of all binders are shown in Tables 1 and 2, correspondingly.

2.2. Fine aggregate- manufacturing sand (M-sand)

M-sand was collected from the local quarry dust industry of

Table 2
Physical properties of constituent materials.

Properties	Materials		
	MK	GGBS	POFA
Specific gravity (Islam et al., 2014)	2.50	2.89	2.20
Specific surface area (m^2/kg) (by particle size analysis)	4315.8	405	172
Colour (visual check)	Off-white	Off-white	Dark