Construction and Building Materials 161 (2018) 365–373

Contents lists available at ScienceDirect

Construction and Building Materials

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

Properties of metakaolin-high calcium fly ash geopolymer concrete containing recycled aggregate from crushed concrete specimens

Peem Nuaklong, Vanchai Sata *, Prinya Chindaprasirt

Sustainable Infrastructure Research and Development Center, Department of Civil Engineering, Faculty of Engineering, Khon Kaen University, Khon Kaen 40002, Thailand

HIGHLIGHTS

- High calcium fly ash (HCF) blended with metakaolin (MK) for geopolymer binder.
- Properties of geopolymer concrete containing recycled coarse aggregate (RAGC) were evaluated.
- The results compared with those of natural aggregate geopolymer concrete (NAGC).
- Increasing MK leads to higher strengths in both NAGC and RAGC.
- MK produces RAGC that is comparable in terms of mechanical performance to NAGC.

ARTICLE INFO

Article history:
Received 15 May 2017
Received in revised form 28 November 2017
Accepted 28 November 2017

Keywords:
Recycled aggregate
High calcium fly ash
Metakaolin
Geopolymer concrete

ABSTRACT

This study aims to investigate the effects of metakaolin (MK) on the properties of a fly ash-based geopolymer concrete containing 100% recycled coarse aggregate from crushed specimens of laboratory. The MK was used as a partial replacement for high calcium fly ash (HCF) in geopolymer binders. The results showed that geopolymer concrete with MK has better strength, porosity, water absorption, and acid resistance. Increasing the use of MK leads to higher strengths in both natural and recycled aggregate geopolymer concrete. Furthermore, the high calcium fly ash blended with MK geopolymer concrete containing recycled aggregate is suitable for environment friendly construction and is comparable in terms of mechanical performance to a normal geopolymer concrete made with natural aggregate.

1. Introduction

Concrete wastes are generated from the demolition of buildings, bridges, sidewalks, etc. [1]. These wastes can be used as aggregates in new concrete to reduce the consumption of natural aggregates, which are non-renewable materials [2–4]. However, it is well known that the porous nature of old cement mortar attached to the surface of recycled concrete aggregate (RCA) plays an important role in concrete properties [5]. Etxeberria et al. [6], Sagoe-Crentsil et al. [7], and Tabsh and Abdelfatah [8] reported that the compressive strength of Portland cement concrete made with 100% RCA was 10–40% lower than that of natural aggregate concrete (NAC). In addition, Marinković et al. [9] found that water absorption and drying shrinkage increased up to 50% relative to conventional concrete. This occurred because old cement mortar has low density, high water absorption, and a high proportion of impurities [10–12].

Geopolymer concretes are manufactured from aluminosilicate minerals activated with alkaline solutions to form a binder [13]. Although the heat curing of geopolymer systems needs some energy input, this cementless concrete is found to be one of the better alternatives for ordinary Portland cement (OPC) concrete in terms of reducing the high CO_2 footprint of OPC production. In addition, geopolymer binders can solve waste disposal problems because they can be produced from industrial wastes such as fly ash, ground granulated blast furnace slag (GGBFS), and mine waste [14]. Recently, Shi et al. [15] and Nuaklong et al. [16] investigated the combined effects of RCA and geopolymer binders in term of their environmental benefits and concrete sustainability. However, the negative effects of recycled coarse aggregate on the properties of geopolymer concrete were similar to those of Portland cement concrete.

The properties of a fly ash based geopolymer binder can be improved by increasing the fineness of the fly ash. This increases the degree of geopolymerization because of its highly reactive surface [17,18]. Some studies have advised the addition of calcium-rich materials such as OPC and GGBFS to improve the setting time

* Corresponding author.
E-mail address: vancsa@kku.ac.th (V. Sata).

https://doi.org/10.1016/j.conbuildmat.2017.11.152
0950-0618/

and early age strength properties of concrete [19,20]. Calcined kaolin, or metakaolin (MK), is a mineral admixture that contains both silica and alumina, which has been utilized for many years in Portland cement concrete. The improved concrete mechanical properties and durability are attributed to the incorporation of MK because of its high pozzolanic reactivity and filling effects [21,22]. Although Duan et al. [23] investigated the mechanical properties and microstructure of fly ash geopolymer paste blended with MK, the study on the inclusion of MK to improve the performance of geopolymer concrete containing RCA has not been reported.

Thus, this study aimed to investigate the effects of high calcium fly ash (HCF) blended with MK on the mechanical properties and durability of recycled aggregate geopolymer concrete (RAGC). The experimental results were compared with those for a natural aggregate geopolymer concrete (NAGC).

2. Materials and experimental details

2.1. Materials

HCF was used as the primary source material for the preparation of hybrid geopolymer concretes. MK was prepared from the calcination of kaolin at 600 °C for 3 h and then ground to the desired fineness with a ball mill. This calcined kaolinite condition was recommended by Provis et al. [24]. The specific gravities of HCF and MK were 2.43 and 2.51, respectively. The chemical properties and fineness of characteristics of source materials are given in Table 1. HCF contains principally 36.2% SiO_2, 19.9% Al_2O_3, 14.2% CaO, and some amounts of SO_3 (3.57%), which meets the requirements of ASTM C618 [25]. Although, it has been reported that the SO_3 in fly ash does not contribute to ettringite formation in heat cured geopolymer systems [26], it is possible that the area locally close to recycle aggregate with high SO_3 content, delayed ettringite formation might occur. For MK, the major chemical compositions were SiO_2 and Al_2O_3. The amount finer than 45 μm (No. 325) sieve of HCF and MK were 65.2 and 98.0% with Blaine fineness of 2100 and 15200 cm^2/g, respectively.

Single-size 4.5–9.5 mm crushed limestone and crushed concrete were used as coarse aggregate. For fine aggregate, natural river sand with 93.5% passing the 2.36 mm (No. 8) sieve and 76.2% passing the 1.18 mm (No. 16) sieve was used in all mixes. Their physical and mechanical properties are listed in Table 2. Recycled concrete aggregate (RCA) was obtained from laboratory-tested concrete samples with compressive strengths ranging from 30 to 40 MPa. The specific gravity and compacted dry density of RCA were lower than that of crushed limestone, while the water absorption and abrasion loss values were higher. This was attributable to the presence of residual cement mortar on the surface of these aggregates.

Table 1
Chemical composition and fineness characteristics of source materials.

Composition (wt.%)	High calcium fly ash (HCF)	Metakaolin (MK)
SiO_2	36.2	47.8
Al_2O_3	19.9	37.1
CaO	14.2	1.77
FeO_3	11.9	1.48
Na_2O	1.15	–
TiO_2	0.48	–
MgO	1.88	0.76
K_2O	2.41	1.68
SO_3	3.57	–
LOI	0.40	5.40
Retained in sieve No. 325 (%)	34.8	2.0
Blain fineness (cm^2/g)	2100	15200

Table 2
Properties of fine and coarse aggregates.

Property	Limestone (L)	Recycled concrete (C)	River sand
Specific gravity (SSD)	2.65	2.30	2.63
Compacted dry density (kg/m^3)	1511	1270	1764
Water absorption (%)	0.61	5.97	1.07
Los Angeles abrasion (%)	33.9	38.8	–
Fineness modulus	6.0	6.0	2.6

2.2. Mixing procedure and preparation of specimens for the geopolymer concrete

The mix proportions of geopolymer concrete are shown in Table 3. The alkaline-solution-to-binder and Na_2SiO_3-to-NaOH mass ratios for all mixes were fixed at 0.6 and 1.5, respectively. HCF was partially replaced with MK at percentages of 0, 10, 20, and 30, by weight.

A series of geopolymer concrete mixtures cases is presented in Table 3. In series I, natural limestone was used as the coarse aggregate in four NAGC mixes (0MK-L, 10 MK-L, 20 MK-L, and 30 MK-L). For series II, four similar mixes (0MK-C, 10 MK-C, 20 MK-C, and 30 MK-C) were prepared with 100% coarse recycled aggregate, to obtain eight mixes. The initial label numbers (i.e., "0", "10", "20", or "30") represent the percentage of MK in the binder. The final label letters "L" and "C" indicate that the concrete mixtures were cast using limestone aggregates or recycled concrete aggregates, respectively.

Fly ash and MK were first manually dry mixed. Then, they were added to a 12 M sodium hydroxide (NaOH) solution and mixed in a concrete mixer for 5 min. Saturated surface dry (SSD) fine and coarse aggregates were mixed together for 5 min. Finally, sodium silicate (Na_2SiO_3) with 12.33% Na_2O, 30.33% SiO_2, and 57.34% H_2O was added, and mixing continued for 5 min. The fresh concrete was cast into steel molds in two layers. Each layer was compacted 25 times with a standard steel rod. Before being cured in an oven at 60 °C for 2 d [27], the samples were kept at room temperature for 1 h (to enable setting) and were wrapped with plastic film to prevent water loss by evaporation during the elevated temperature curing process [28]. Then, the demolded samples were sealed with a plastic sheet and placed in a temperature-controlled room at 22–25 °C and 50–55% RH until the testing day.

2.3. Specimens and testing

2.3.1. Workability

The properties of the fresh geopolymer concrete were determined using a slump flow method according to ASTM C1611 [29]. When the mixing procedure was completed, the mold was immediately fill with concrete and then lifted vertically. After the flow of concrete was stopped, the flow diameter was measured using a steel tape.

2.3.2. Strengths of the hardened geopolymer concrete

Following previous work with the rate of strength development of geopolymer system increased at early age due to heat curing [16], thus the compressive strength (ASTM C39) [30] and tensile strength (ASTM C496) [31] were measured after 7 d for concrete cylinders 100 mm in diameter and 200 mm in height. The samples were cast into prisms measuring 75 × 75 × 300 mm to determine their flexural strength (ASTM C78) [32].